LACIE-00424
JSC-11336

LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

NASA NOAA USDA

RESULTS OF LACIE INTEGRATED DROUGHT ANALYSIS

(SOUTHERN U.S. GREAT PLAINS DROUGHT 1975-76)

(NASA-TM-X-74640) LARGE AREA CROP INVENTORY EXPERIMENT (LACIE). RESULTS OF LACIE INTEGRATED DROUGHT ANALYSIS (SOUTHERN U.S. GREAT PLAINS DROUGHT 1975-76) (NASA) 76 p HC A05/MF A01 CSCL 04A G3/43

N77-20544

Unclas 22840

National Aeronautics and Space Administration

LYNDON B. JOHNSON SPACE CENTER

Houston, Texas

JULY, 1976

LARGE AREA CROP INVENTORY EXPERIMENT (LACIE)

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(SOUTHERN U.S. GREAT PLAINS DROUGHT 1975-76)

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July 1976

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1.0 Introduction

The development and intensification of the drought in the United States southern Great Plains was monitored during the initial growing period (biowindow 1, i.e., between emergence and jointing) of the 1975-76 winter wheat crop. Because of the severity of the drought conditions, a Drought Analysis Plan (LACIE-00613) was developed by the LACIE (Large Area Crop Inventory Experiment) Episodal Events Team and approved by the LACIE Manager on March 5, 1976. The implementation of the plan began on March 8, 1976.

The technical approach involved the use of LACIE sample segments (5 x 6 nmi) and full-frame imagery (100 x 100 nmi) on 9-day intervals to identify the drought area and quantify the effects on the wheat acreage. Yield model simulations were run to extrapolate the effects of the drought on yield estimates at harvest, assuming 10 and 90 percent of normal rainfall for subsequent months and 30-day forecast. A survey of Landsat data for improvement of distribution of rainfall patterns in the drought area was done for April and yield models run for drought affected crop reporting districts (CRD's). Special aggregations were performed by the CAS (Crop Assessment Subsystem) on the drought area to evaluate the utility of remote sensing to monitor the effect of the drought on wheat area, yield, and production. This report summarizes the results of the LACIE analysis for the 1975-76 winter wheat drought in the southern Great Plains.

1.1 Objectives

The objectives of monitoring the drought episodal event were to determine the extent of the 1975-76 drought in the southern Great Plains, to determine the effects of this drought upon acreage, yield, and production of wheat, and to develop procedures for monitoring drought using remote sensing based criteria.

1.2 Definition of Agricultural Drought

Drought is a condition when precipitation drops far enough below the normal amount to cause a serious hydrologic imbalance in the affected area. The effects vary from slight reductions in size, vigor, and yield, to outright killing of the plants from soil blowing caused by lack of vegetative cover as well as lack of moisture.

For this study, the initial drought area was assumed to be located within the 50 percent or less of normal precipitation isoline for the period December 1975 to February 1976 (figure 1). Within this 50 percent isoline, a 25 percent or less of normal precipitation isoline was also determined. As the study proceeded, it became apparent that the entire area within the 50 percent isoline was not affected. The area outlined affected by drought determined from full-frame corresponds closer to the 25 percent isoline than the 50 percent isoline. If a 30 percent of normal precipitation isoline had been used, it would have delineated the general area affected by drought fairly well.

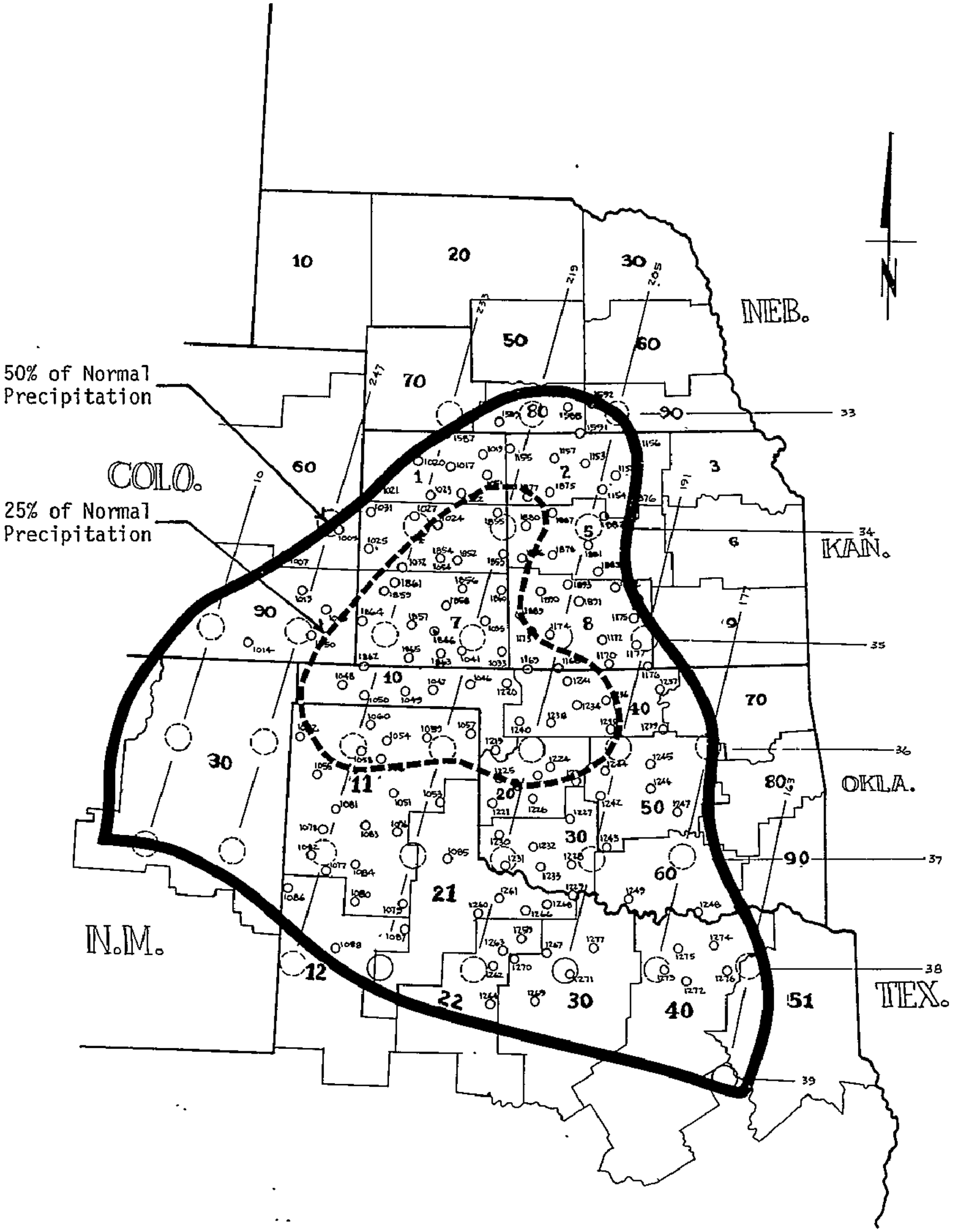

Figure 1. Initial Drought Area as Determined by Meteorological Data with crop reporting districts, segment location and Landsat orbit passes location. (See Appendix for old CRD numbers)

1.3 Background of 1975-76 Drought

The 1975-76 winter wheat drought goes back to the summer of 1975 when the soil moisture supply was not recharged after the 1974-75 harvest. This acute moisture shortage caused a period of over 30 days duration between planting and emergence (figure 2). During the 1975 Thanksgiving week, a major storm system moved through the Great Plains bringing blizzard conditions to portions of the Plains. These cold temperatures caused the winter wheat to go into dormancy allowing very little root or top growth during the relatively brief period after emergence. If rainfall had been normal for the December 1975 through February 1976 period, damage would have been very slight. However, the months of December through February were dry and, with the exception of a brief cold spell in January, unseasonably mild. Seasonably strong winds started to blow in December causing a greater than normal amount of damage for that time of the year. This wind erosion probably caused more damage to the wheat plant than the direct lack of moisture.

1.4 Meteorological Signal for Potential Drought

It is apparent that below normal precipitation can be used to signal the potential for drought damage in winter wheat. While the precipitation for September through October 1975 planting period was

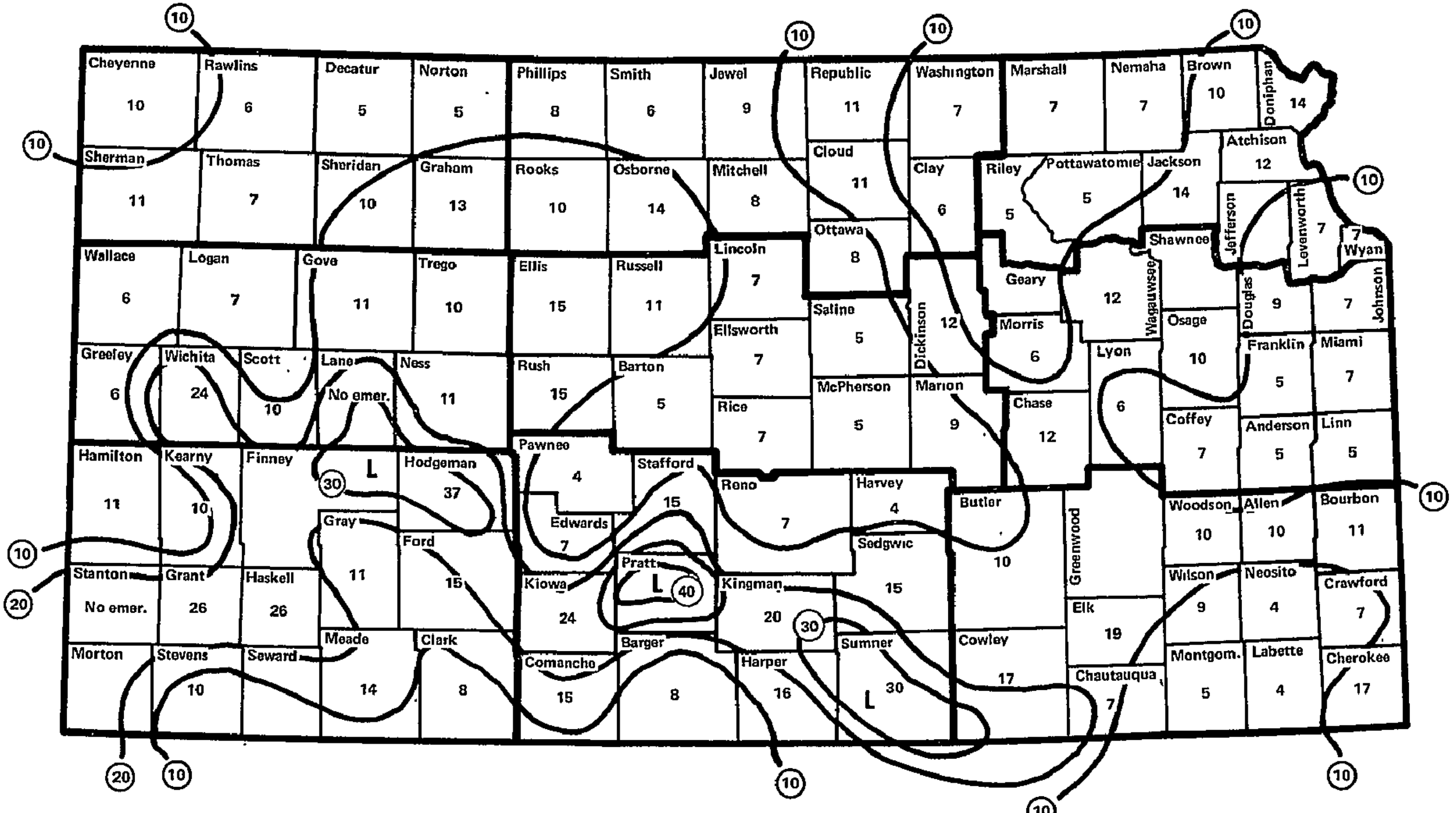

Figure 2.- Duration in days between planting and emergence

below normal (figure 3) for most CRD's, only Kansas CRD 07 and Oklahoma CRD 1 were severely affected in reduction of acreage (table 2, p. 55). The December through February precipitation was below 25 percent of normal for three CRD's (figure 1) also. From this information, we could determine that 25 to 30 percent of average precipitation for approximately 2 months before planting winter wheat would signal the potential for drought damage. A reduction of 25 to 30 percent of average precipitation during dormancy would also signal potential drought damage. A combination of both would indicate severe damage. The drought that affected South Dakota in May through June 1976 has indicated that essentially normal precipitation occurred during winter up through April, however, May was 24 to 33 percent below normal for affected CRD. This indicates that 25 to 30 percent of normal precipitation for one month may flag the necessity to evaluate the potential for drought and a reduction in acreage and yield.

2.0 Areal Extent of Drought

The areal extent of the drought was determined using full-frame color infrared transparencies to refine the area initially located by use of meteorological data. This was determined by subjectively comparing 1976 full-frame imagery to past years' full-frame imagery of essentially the same date. The areal extent was evaluated every 9 days and the degree of drought effect within the affected area was rated low, moderate, and severe.

PRECIPITATION TOTALS SEPT - OCT

(IN INCHES)

STATE & CRD	SEPT	OCT	TOTAL	SEPT-OCT % OF NORM
KS 01 NORTHWEST	.98 (1.78)	.05 (1.14)	1.03 (2.92)	35%
KS 04 WEST CENTRAL	1.00 (1.70)	0 (1.19)	1.00 (2.89)	34
KS 07 SOUTHWEST	.19 (1.66)	.03 (1.26)	.22 (2.92)	8
KS 08 SOUTH CENTRAL	.72 (2.92)	.12 (2.09)	.84 (5.01)	17
OK 10 PANHANDLE	.62 (1.79)	.07 (1.43)	.69 (3.22)	21
OK 20 WEST	.93 (2.77)	1.04 (2.24)	1.97 (5.01)	39
OK 40 NORTH CENTRAL	.32 (3.04)	.54 (2.21)	.86 (5.25)	16
OK 30 SOUTHWEST	2.78 (3.11)	1.14 (2.62)	3.92 (5.73)	68
TX 01 PANHANDLE	1.77 (2.11)	.12 (1.71)	1.89 (3.82)	49

( ) 1931-74 NORMALS

FIGURE 3

2.1 Affected Area

The drought affected area was determined from full-frame imagery to be located in the western section of Kansas, southeast Colorado, and the Oklahoma and Texas Panhandles. The affected area as of April 1, 1976, (figure 4) was rated subjectively by comparison with previous years imagery using Landsat I and II imagery acquired during March. Landsat I imagery acquired April 6 through 12, 1976, was used to prepare the April 12, 1976 areal extent (figure 5). It was not possible to estimate the areal extent for the rest of April because of cloud coverage over the drought area. Fairly heavy rains occurred during the May 5 through 8, 1976 overpass and the entire drought area has been green since. The subjective rating for the different Landsat passes varies according to the processing quality of the imagery. An example of the April 1, 1976 compared to imagery of February 8, 1974 indicates that the low, moderate, and severe rating while done subjectively does give a clue to the severity of the drought (figures 6 and 7). The April 10, 1976 image (figure 8) also shows the value of subjectively rating the affected area. Comparing this image with April 16, 1975 (figure 9) shows that the area is definitely drought affected. The April 10, 1976 image also points out the value of having homogeneous entities that represent geographic areas or partitions. If the low, moderate, and severe ratings made from the Landsat imagery are compared to the General Soil Map of Texas (figure 10), these boundaries compare with the soil boundaries extemely well. The low rating compares with soil 60-M which is

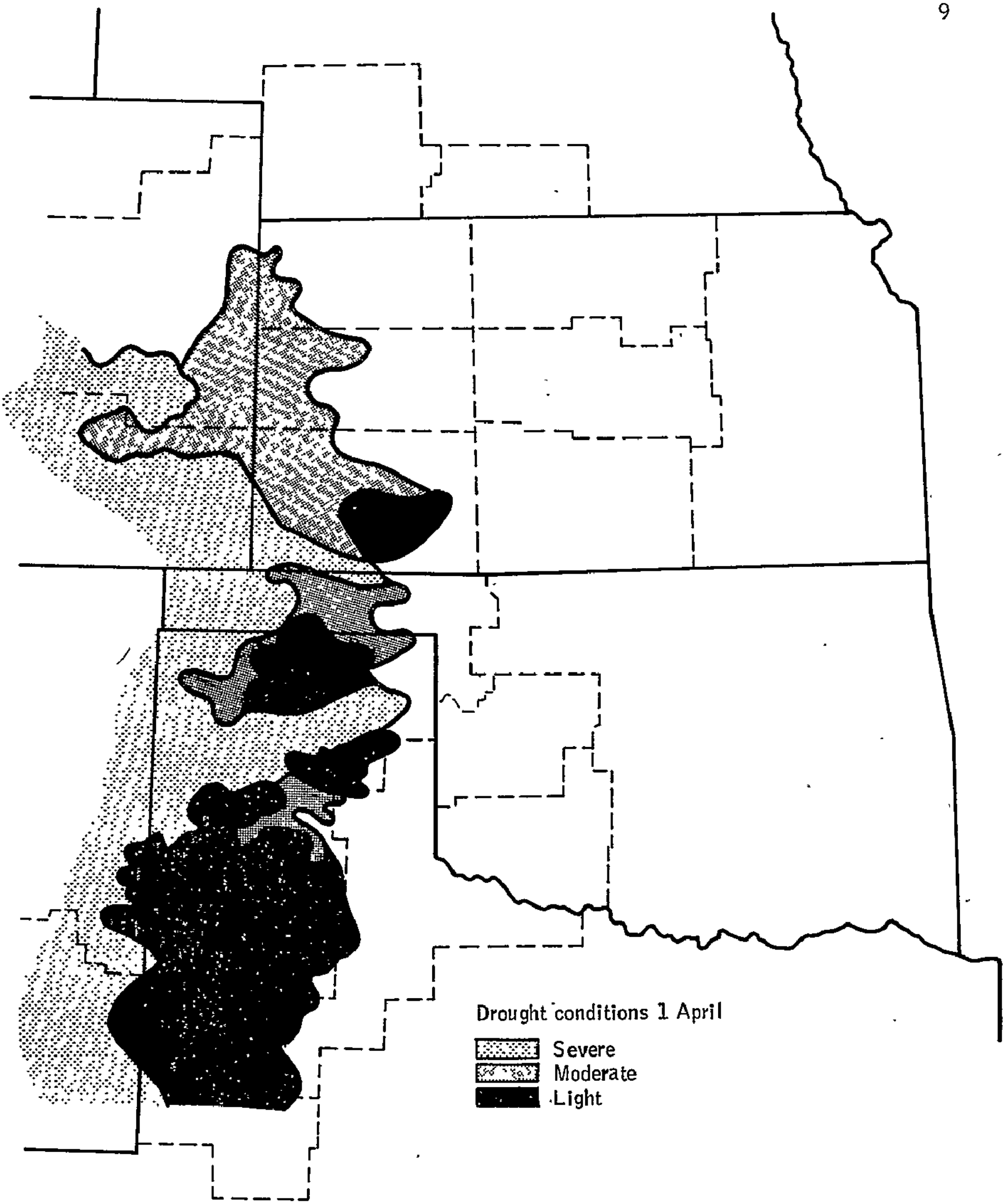

Figure 4. Areal extent and effect of drought on April 1, 1976.

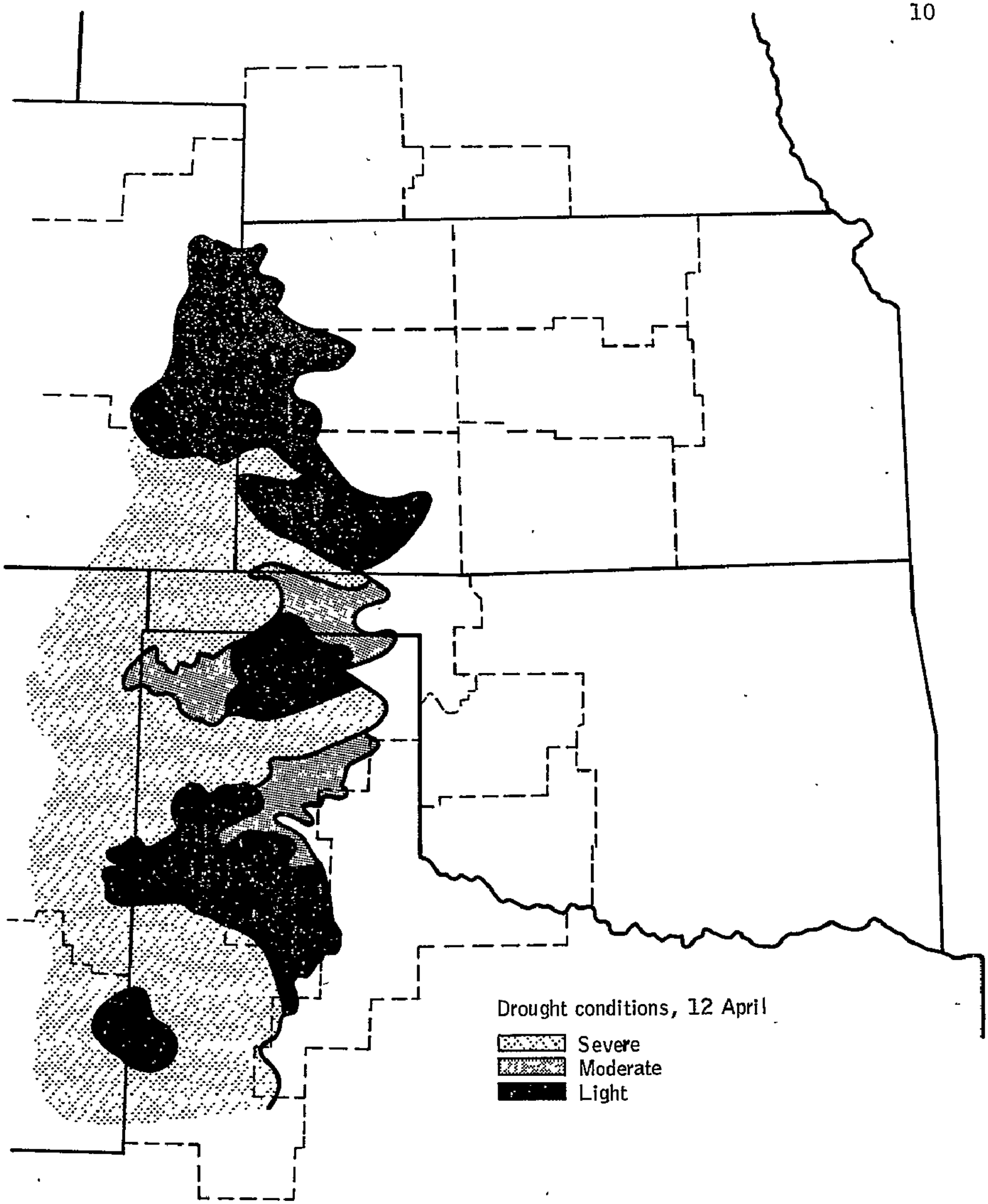

Figure 5. Areal extent and effect of drought on April 12, 1976.

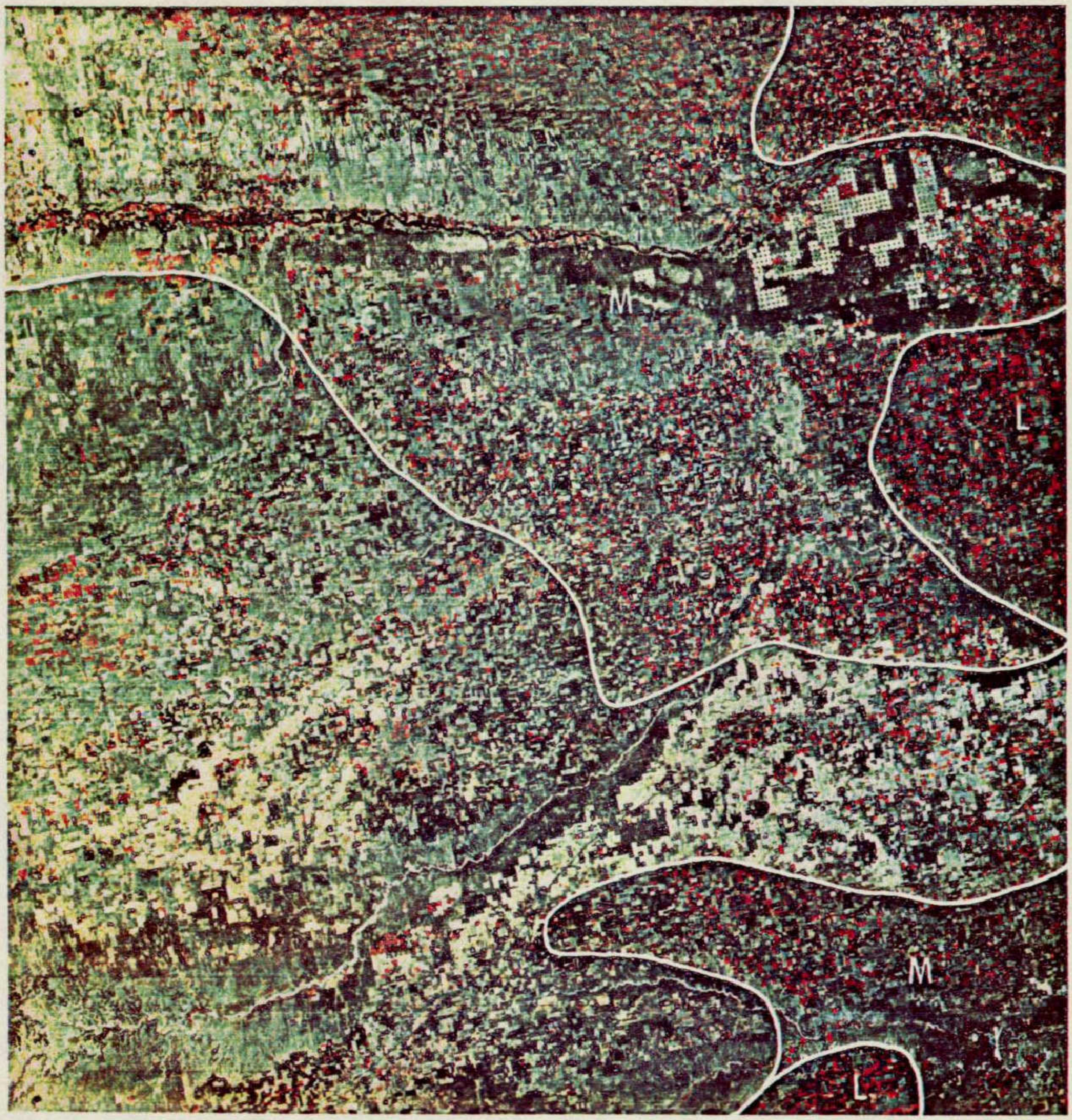

Figure 6. Landsat image acquired April 1, 1976 showing drought conditions.

Figure 7. Landsat image acquired February 8, 1974 showing normal conditions.

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Figure 8. Landsat image acquired April 10, 1976 showing drought conditions.

Figure 9. Landsat image acquired April 16, 1975 showing normal conditions

soils with loamy surface layers and clayey subsoils. The moderate rating corresponds to soil 63-A which is soil mostly loamy throughout with lime accumulation in the subsoil. The severe rating corresponds to soils 46-M and 64-M. Soil 46-M is mostly shallow and moderately deep soils over limy earths. Soil 64-M is mostly clayey throughout with lime accumulation in the subsoil. With this area receiving the same amount of precipitation, the subjective ratings of the full-frame imagery outlined the soil water-holding capacity. With soil supported partitions of this area, the varying effects upon yield could be determined.

2.2 Criteria for Evaluating Areal Delineation

The areal extent determined from Landsat images and the subjective ratings of drought effect were evaluated by comparing them against standard indexes and a specially developed process using Landsat digital data. The Weekly Crop Moisture Index developed each week by the National Weather Service, NOAA, provided an acceptable standard index to compare the aereal extent against. Computer-measured vegetative greenness for wheat and non-wheat on 5 x 6 mile sample segments for selected areas provided another evaluation for the subjective ratings. Sample segments selected for analysis accuracy assessment (blind sites) provided ground truth data for comparison. Each of these methods have been compared to the results obtained from full-frame imagery.

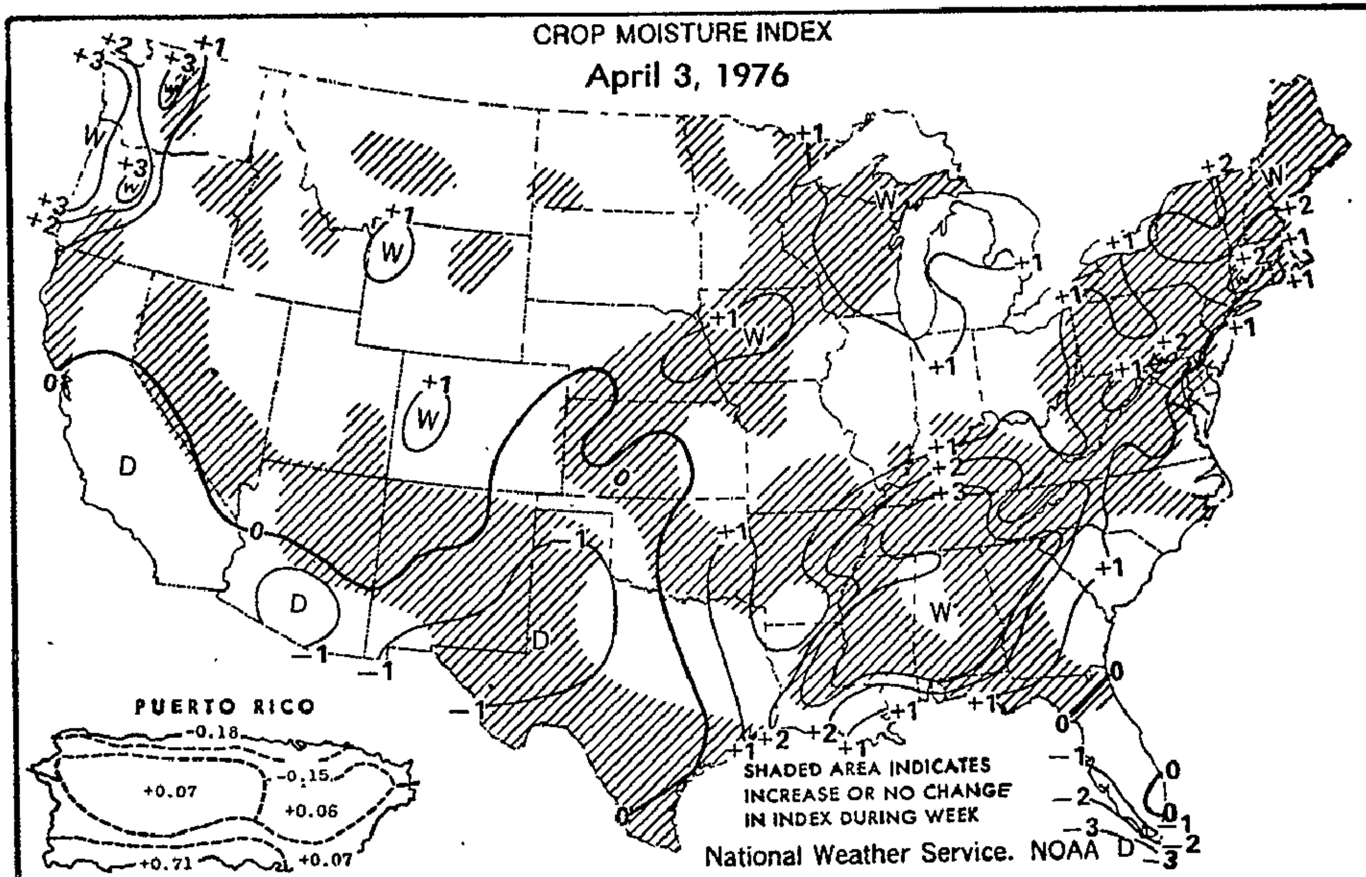
2.2.1 Crop Moisture Index

The Weekly Crop Moisture Index is a measure of the amount of moisture available for crop growth. To understand the Crop Moisture Index, one must understand the meaning of the word "evapotranspiration." Evapotranspiration refers to the amount of water that a crop absorbs through its root system and transpires into the air through the leaves, plus the amount of water evaporated directly from the plant surface or surrounding ground surface. The top layers of the soil act as a reservoir of water from which the evapotranspiration needs of the plant are satisfied. The only input of water into the soil is by precipitation. Computation each week of the comparison of the actual evapotranspiration to the normal (30 year average) of the evapotranspiration for that week provides a measure of the effect of weather on the moisture supply of the crop.

The Crop Moisture Index starts near zero at the beginning of the growing season and ends up at the end of the growing season near zero. This is because the moisture demand by crops is low at these times and the crop moisture values are directly related to the plants' use. Negative numbers indicate a low water supply in the soil and positive numbers indicate an excess of water supply in the soil. Numbers near zero indicate a normal or average moisture condition. A carry-over condition from the previous season is taken into account by determining the amount of water in the soil at the beginning of the growing season.

The Weekly Crop Moisture Index can be used as a guide for crop growing conditions. This index is an average condition applying to a multiple county area, and adjustments must be made to specific areas as to precipitation received and soil moisture holding capacity.

The Crop Moisture Index for April 3, 1976, (figure 11) shows the area affected by drought is limited to the Texas Panhandle region. The 0 to -1 line extends into Kansas and Colorado. This area is defined by the index as having topsoil moisture short, germination slow. Winter wheat should not be under stress with this condition. From areal extent determined from full-frame on April 1, 1976, (figure 4) the comparison of the Crop Moisture Index to this outline does not compare except for general area. The Crop Moisture Index of April 10, 1976, (figure 12) has expanded the "-1" line into the Oklahoma Panhandle. The areal extent from full-frame for April 12, 1976, (figure 5) has the same general outline as the April 1, 1976, extent (figure 4). Thus, from full-frame interpretation, the area affected by drought has remained stable. The April 17, 1976, (figure 13) and April 24, 1976, (figure 14) Crop Moisture Index reports show that the "-1" line has disappeared and a "0" line is located in the Texas-Oklahoma Panhandles, the southwest corner of Kansas, and the southeast corner of Colorado.



The Crop Moisture Index measures the degree to which moisture requirements of growing crops were met during the previous week. The index is computed from average weekly values of temperature and precipitation. These values are used to calculate the potential moisture demand. Taking into account the previous soil moisture condition and current rainfall, the actual moisture loss is determined.

If the potential moisture demand, or potential evapotranspiration, exceeds available moisture supplies, actual evapotranspiration is reduced and the CMI gives a negative value. However, if moisture meets or exceeds demand the index is positive.

Shaded areas indicate the index was unchanged or increased from the previous week's value, soils dried in the unshaded areas. Centers of positive and negative areas are identified by W for wet and D for dry.

Local moisture conditions may vary because of differences in rainfall distribution or soil types The type of agriculture and stage of crop development must be considered when assessing the impact of moisture conditions based on the Crop Moisture Index. Some general guidelines follow.

UNSHADED AREAS:	INDEX DECREASED
ABOVE 3.0	SOME DRYING BUT STILL EXCESSIVELY WET
2.0 to 3.0	MORE DRY WEATHER NEEDED, WORK DELAYED
1.0 to 2.0	FAVORABLE, EXCEPT STILL TOO WET IN SPOTS
0 to 1.0	FAVORABLE FOR NORMAL GROWTH AND FIELDWORK
0 to -1.0	TOPSOIL MOISTURE SHORT, GERMINATION SLOW
-1.0 to -2.0	ABNORMALLY DRY, PROSPECTS DETERIORATING
-2.0 to -3.0	TOO DRY, YIELD PROSPECTS REDUCED
-3.0 to -4.0	POTENTIAL YIELDS SEVERELY CUT BY DROUGHT
BELOW -4.0	EXTREMELY DRY, MOST CROPS RUINED

SHADED AREA	INDEX INCREASED OR DID NOT CHANGE
ABOVE 3.0	EXCESSIVELY WET, SOME FIELDS FLOODED
2.0 to 3.0	TOO WET, SOME STANDING WATER
1.0 to 2.0	PROSPECTS ABOVE NORMAL, SOME FIELDS TOO WET
0 to 1.0	MOISTURE ADEQUATE FOR PRESENT NEEDS
0 to -1.0	PROSPECTS IMPROVED BUT RAIN STILL NEEDED
-1.0 to -2.0	SOME IMPROVEMENT BUT STILL TOO DRY
-2.0 to -3.0	DROUGHT EASED BUT STILL SERIOUS
-3.0 to -4.0	DROUGHT CONTINUES, RAIN URGENTLY NEEDED
BELOW -4.0	NOT ENOUGH RAIN, STILL EXTREMELY DRY

Figure 11. Crop Moisture Index for April 3, 1976.

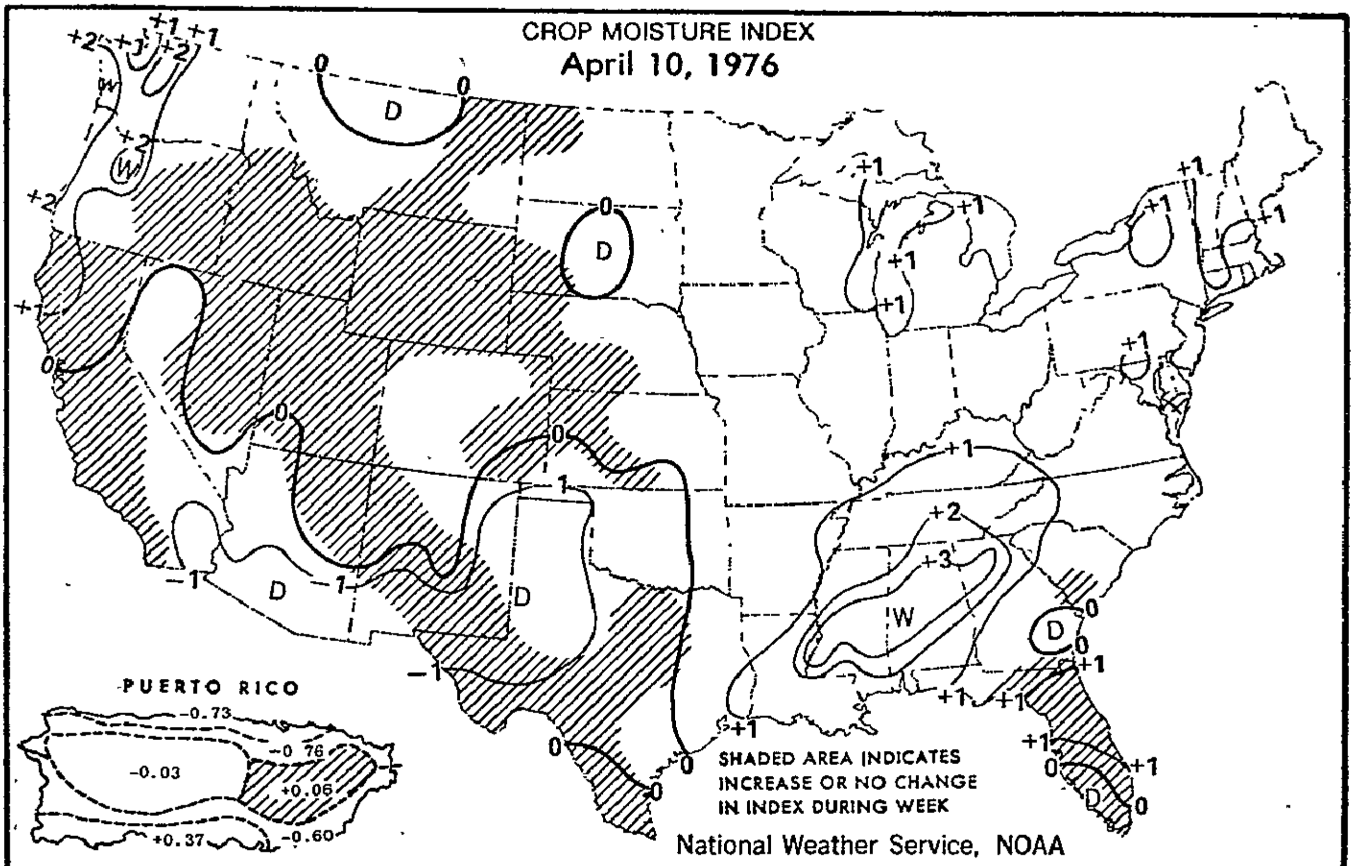


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Figure 12. Crop Moisture Index for April 10, 1976

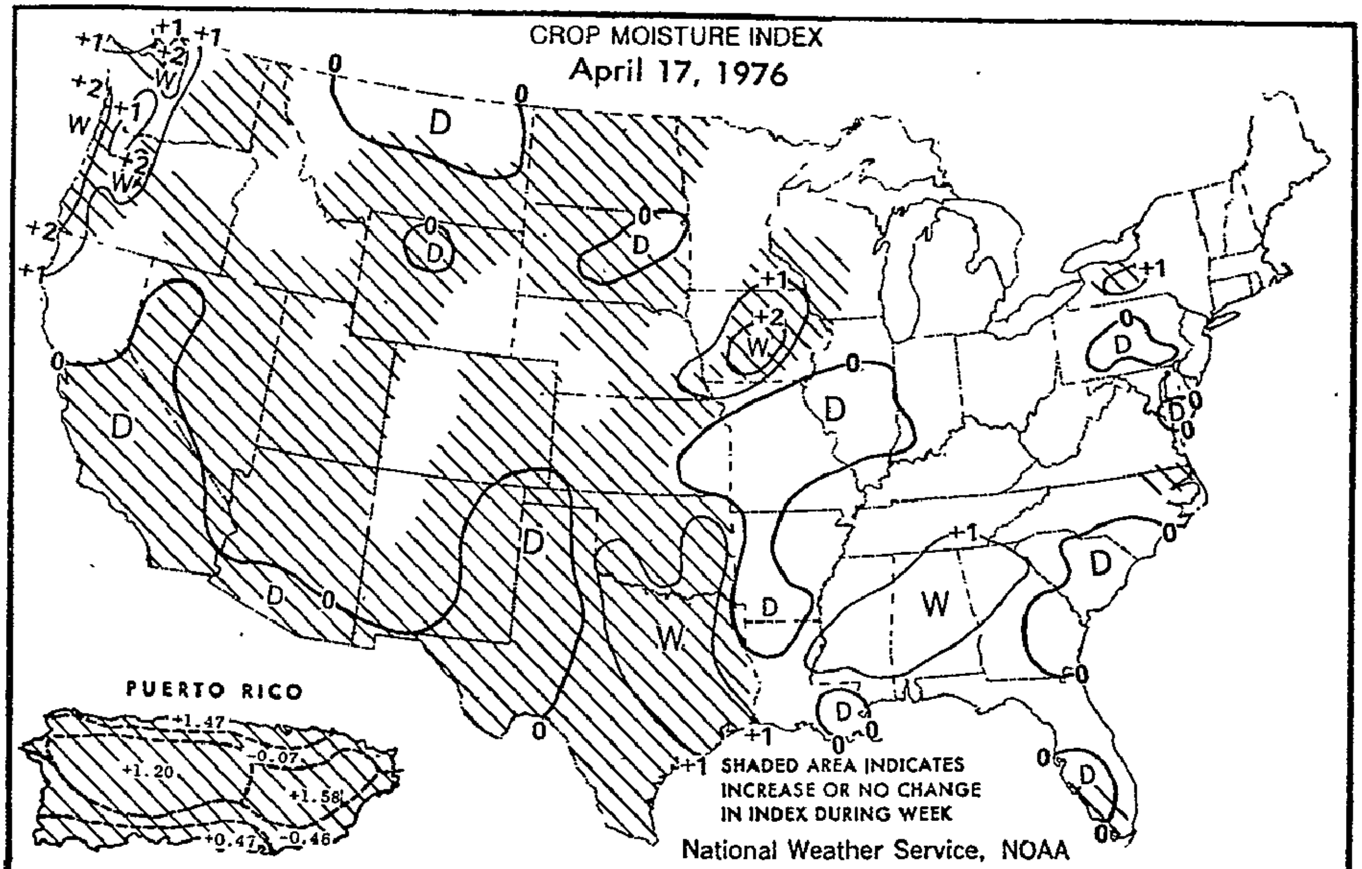

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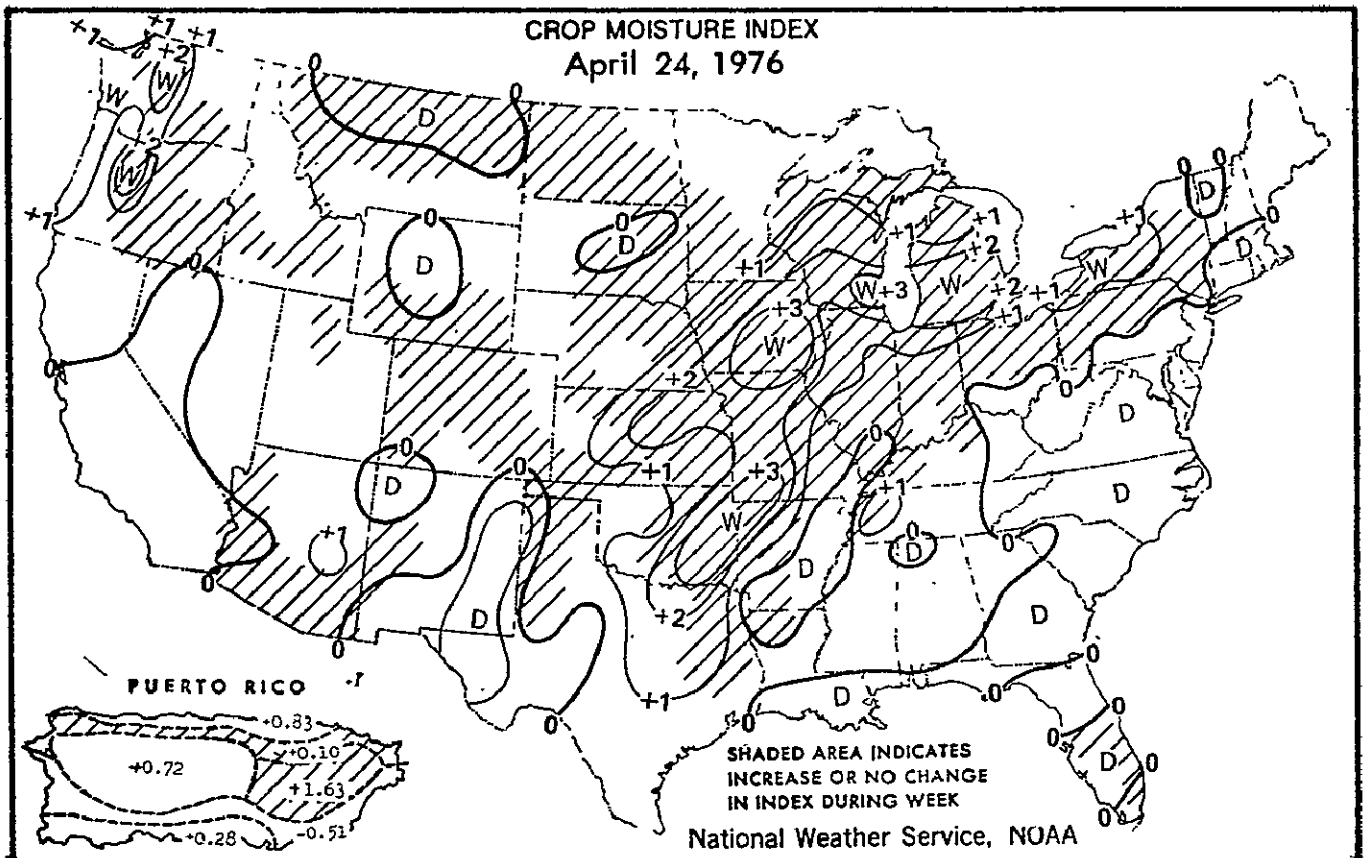
Figure 13. Crop Moisture Index for April 17, 1976



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-3.0 to	-4.0	DROUGHT CONTINUES, RAIN URGENTLY NEEDED
BELOW	-4.0	NOT ENOUGH RAIN, STILL EXTREMELY DRY

Figure 14. Crop Moisture Index for April 24, 1976.

From these reports, one can assume that crop moisture conditions are near normal. This "O" (April 24) line also corresponds closely to the area extent of drought as determined from full-frame. It was during the last of April that precipitation occurred over the drought area.

2.2.2 Vegetative Greenness

As drought affects the hydrologic imbalance of vegetation and thus reduces the amount of green vegetation present, one method of evaluating if an area is affected is by measuring crop vigor. Kauth (NASA memo TF3-75-5-190) has suggested a linear combination of the Landsat channels which changes the four Landsat channel values to four other values with agricultural interpretation. These agricultural related values are 'brightness,' 'greenness,' 'yellowness,' and 'none such.' The transformation is given in figure 15.

If the greenness and brightness are plotted (figure 16) and none such and yellowness (figure 16) plotted, the result indicates that the yellowness and none such are noise in most scenes. Yellowness has agricultural information at near harvest only. Greenness is a direct measure of green vegetation.

To evaluate the areal extent determined from full-frame imagery, selected 5 nmi x 6 nmi sample segments within and outside the outlined drought area were used to measure the vegetative greenness. AI-selected wheat and non-wheat fields were used

FIGURE 15

$$\begin{pmatrix} \text{BRIGHTNESS} \\ \text{GREENNESS} \\ \text{YELLOWNESS} \\ \text{NONE SUCH} \end{pmatrix} = \begin{pmatrix} 0.43258 & 0.63248 & 0.58572 & 0.26414 \\ -0.28972 & -0.56199 & 0.59953 & 0.49070 \\ -0.82418 & 0.53290 & -0.05018 & 0.18502 \\ 0.22286 & 0.01249 & -0.54311 & 0.80945 \end{pmatrix} \begin{pmatrix} \text{CH1} \\ \text{CH2} \\ \text{CH3} \\ \text{CH4} \end{pmatrix}$$

BRIGHTNESS	SUM OF CHANNELS
GREENNESS	IR. MINUS VISIBLE
YELLOWNESS	RED MINUS GREEN
NONE SUCH	CH 4 - CH 3

THE MATRIX IS ORTHOGONAL

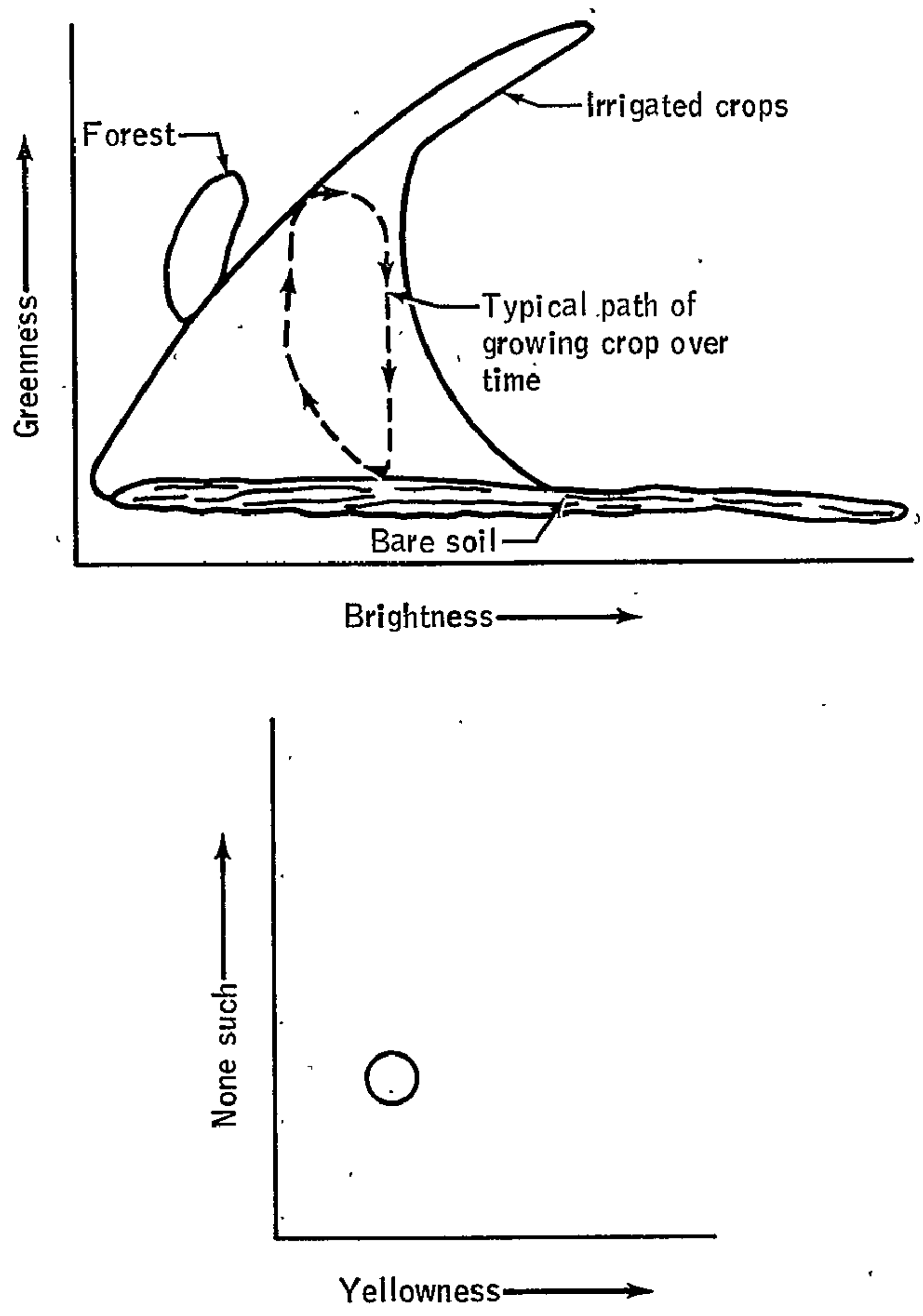

Figure 16. Sketch of the region occupied by typical agricultural data.

to compute the vegetative greenness for every acquisition during the 1975-76 crop year. The overall greenness of the segment was also determined. For whole segments, percent of pixels in clusters whose green number was greater than 5, the "percent green" was computed. To partially correct for atmospheric effects, the green number was defined as the difference between greenness and minimum greenness for the segment clusters. Data is available on individual wheat fields over the crop year which show the steadily deteriorating condition within the drought area. Only a few select sample segments are presented in this report (figure 17).

In order to be 100 percent green, the AI-selected fields have to have a green value greater than 5. This requires very little ground cover. From figure 18, segment 1048 was affected by dry conditions in the fall and never did green up in the spring. The entire segment was never very green and when normal greening up should have occurred, it did not. Segment 1056 (figure 19), in a low rated area, does show that normal greening up occurred in the spring, indicating that subsoil moisture was available. The wheat was green throughout the growing season. However, most wheat in this area is irrigated.

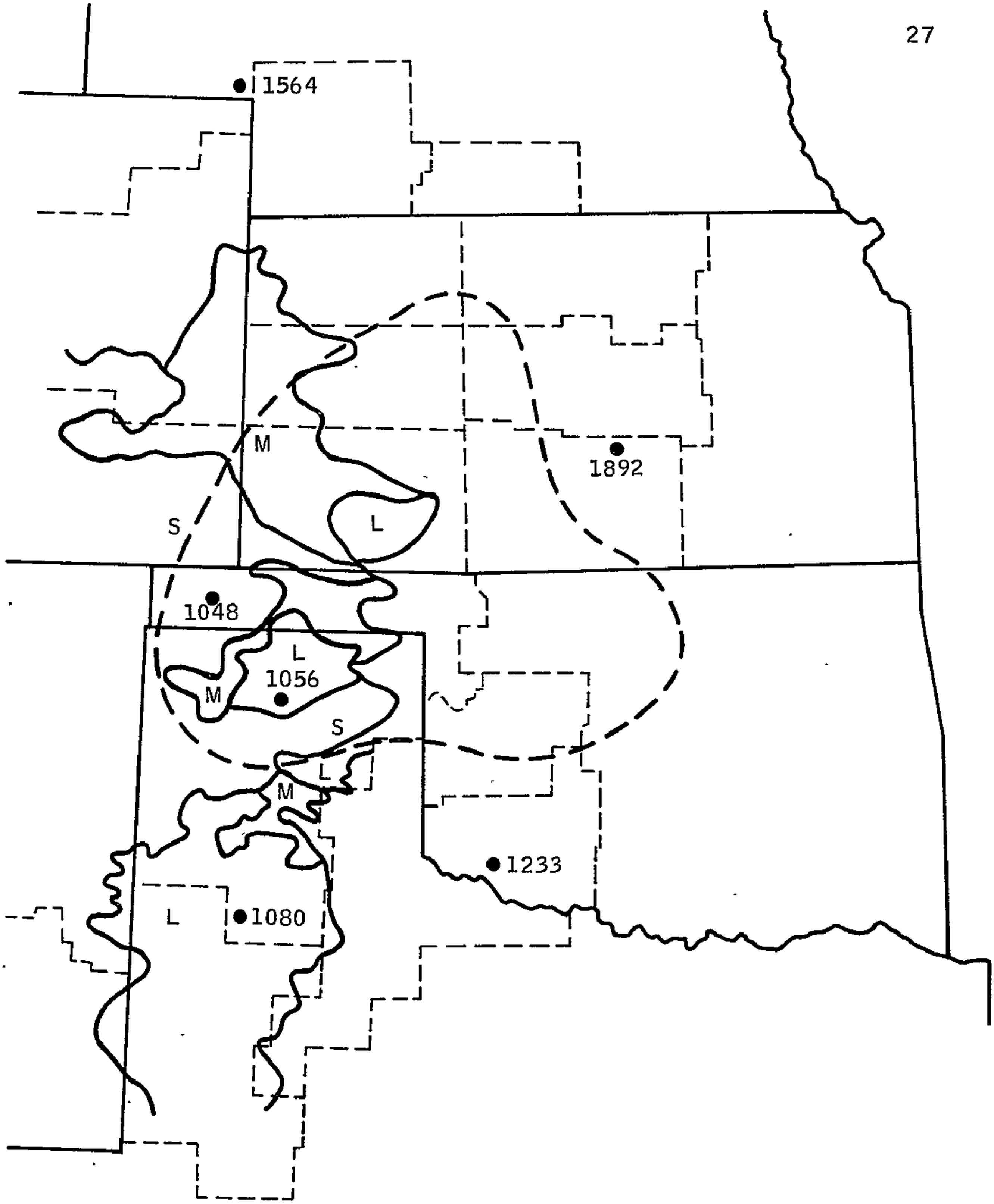

Figure 17. Location of sample segments for vegetation greenness measurements

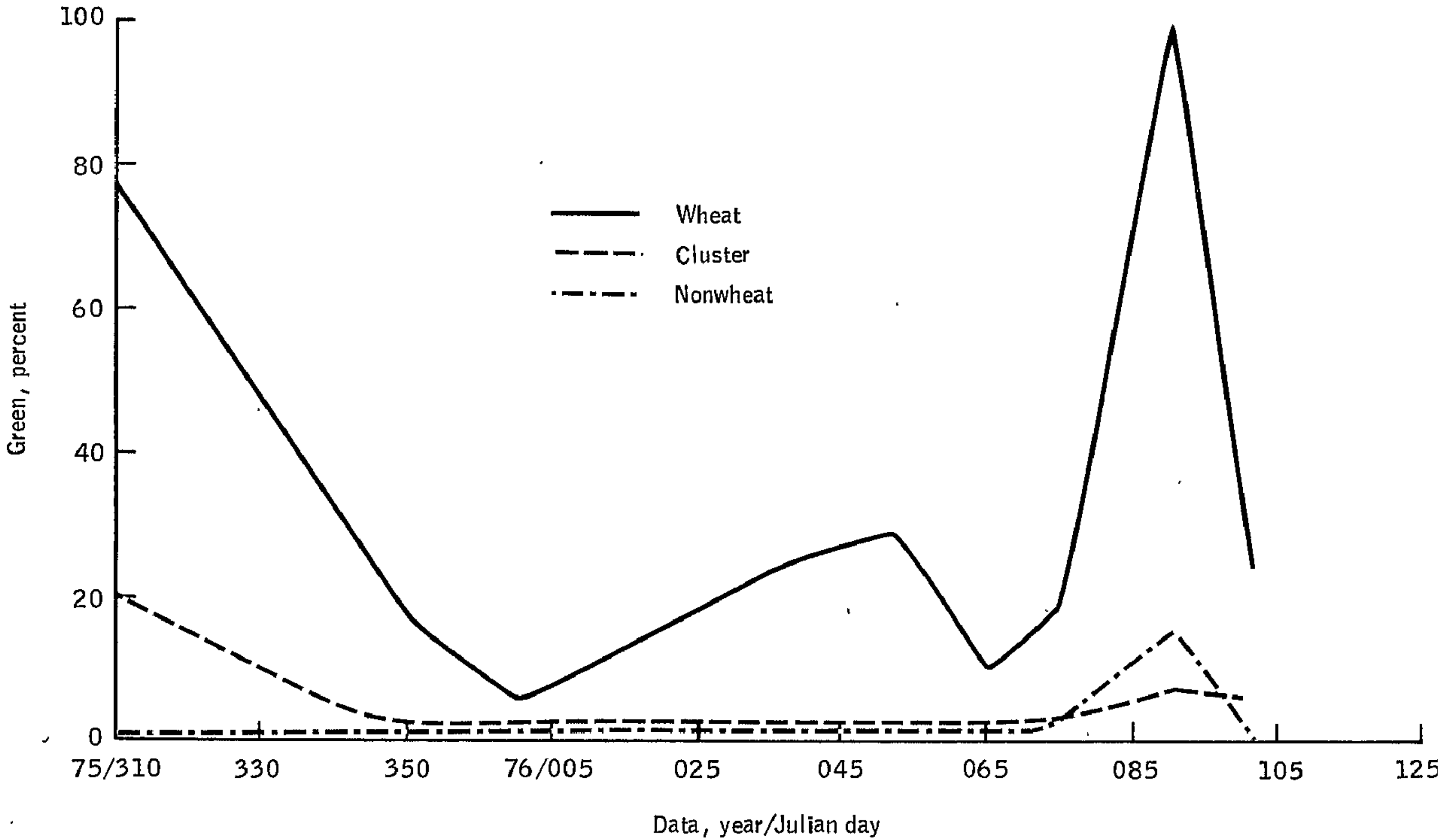

Figure 18. Drought effects upon segment 1048.

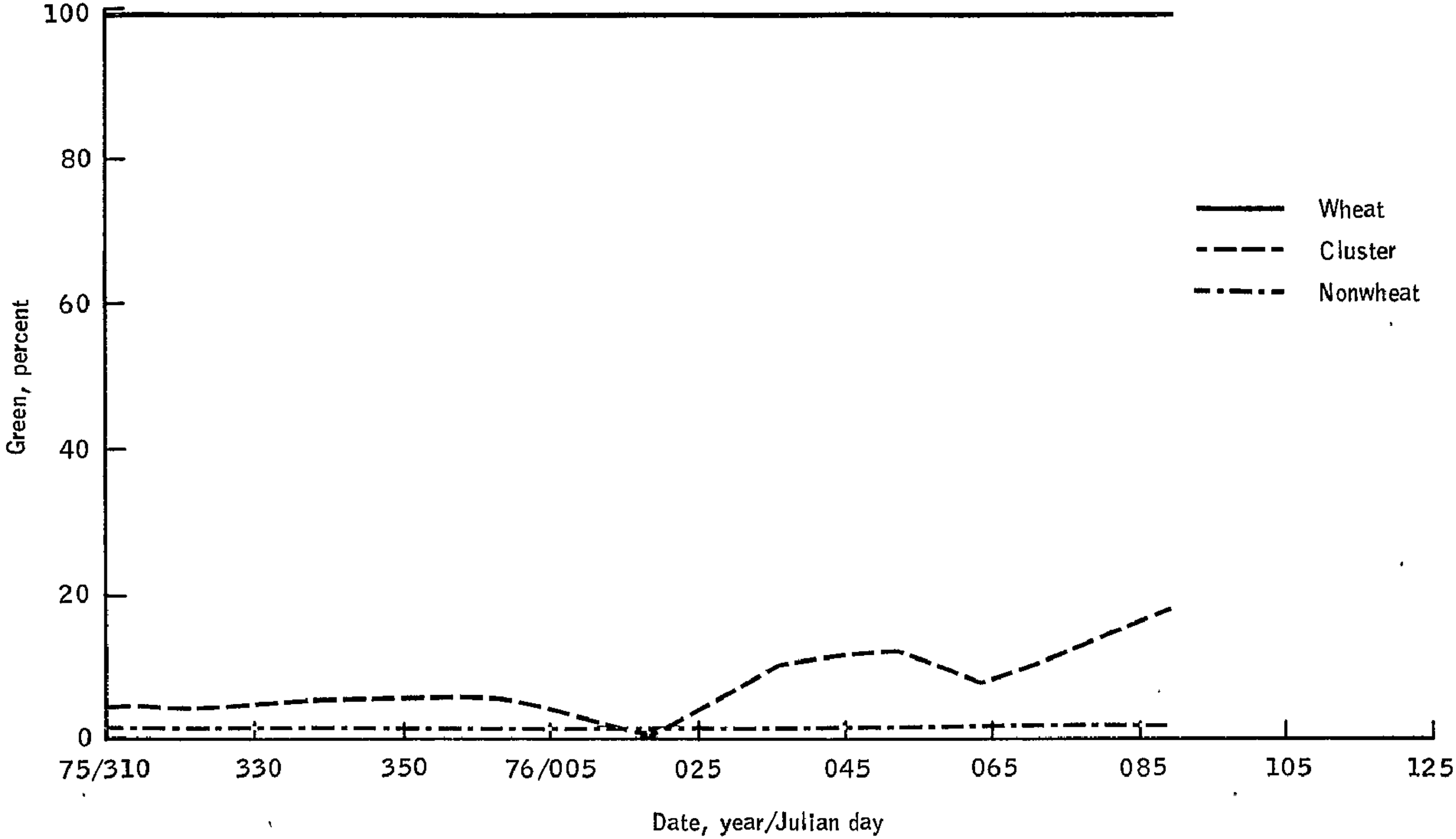

Figure 19. Drought effects upon segment 1056.

Segment 1233 (figure 20) and segment 1892 (figure 21) indicate that the overall scene is very green, adequate moisture is available, normal greening-up in spring occurred, and never during the crop year was moisture not available. AI-selected wheat fields were green and did not experience a decline in vigor through the crop year. If individual wheat fields are plotted for an affected segment (1080) and a non-affected segment (1564) figure (22) for 1976 and 1975, segment 1080's wheat fields are down approximately 40 to 50 percent this year in vigor. The non-affected segment 1564 is somewhat bettern in 1976 than 1975.

2.2.3 Blind Sites

Blind sites over the drought area were evaluated for drought effect. The overall statements concerning drought on these sites support the results from the full-frame delineations and also the acreage reduction indicated by LACIE CAMS operations. However, because of the drought, 35 of the original 40 blind sites in the Great Plains are being reevaluated as to the effect that drought had. When this data is available, a more accurate evaluation can be made.

2.3 Problems of Areal Delineation

Several problems arose during the delineation of the area affected by drought from the full-frame Landsat imagery. These were primarily due to processing inconsistency, no Landsat coverage, or cloud

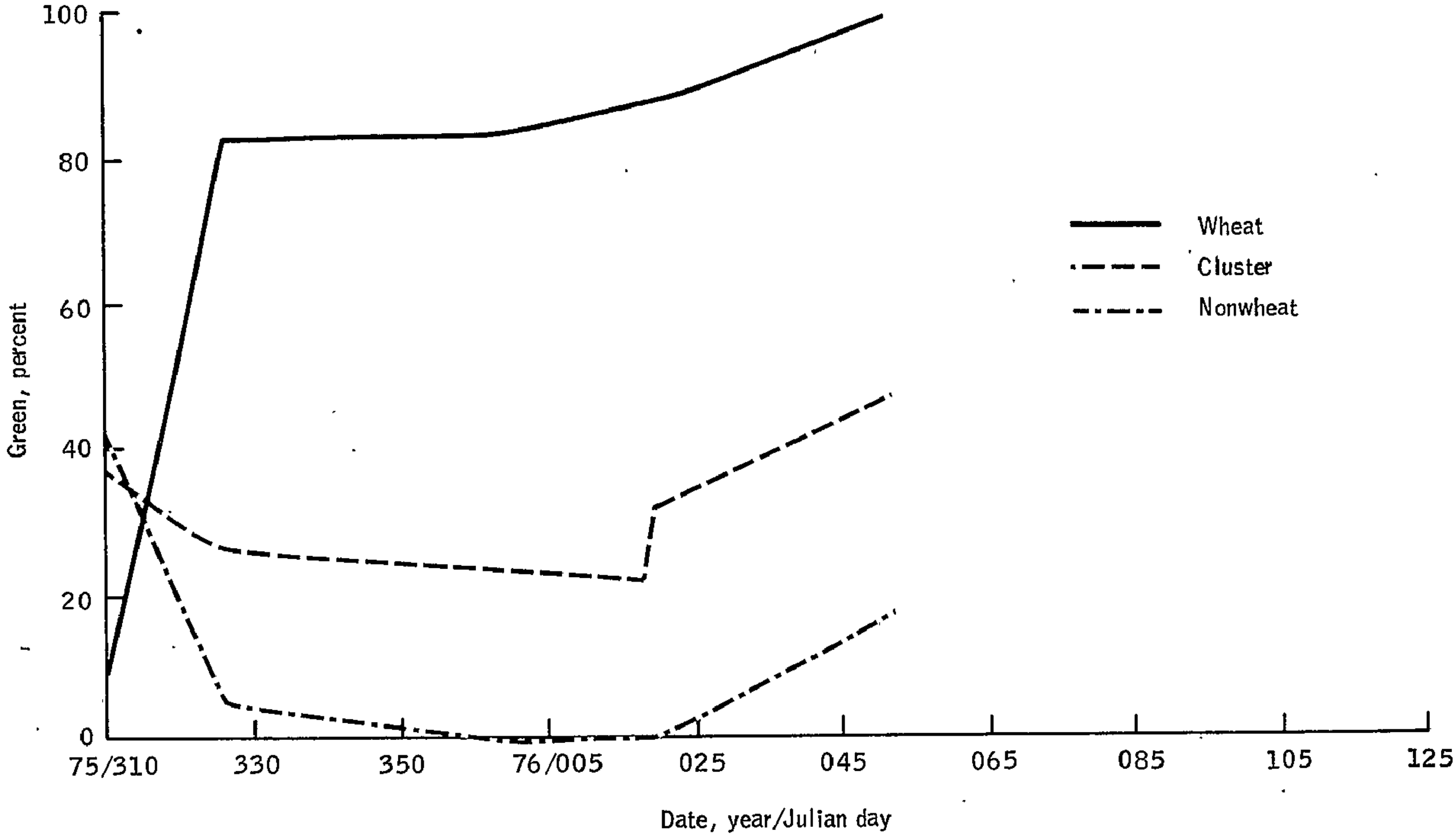

Figure 20. Drought effect upon segment 1233.

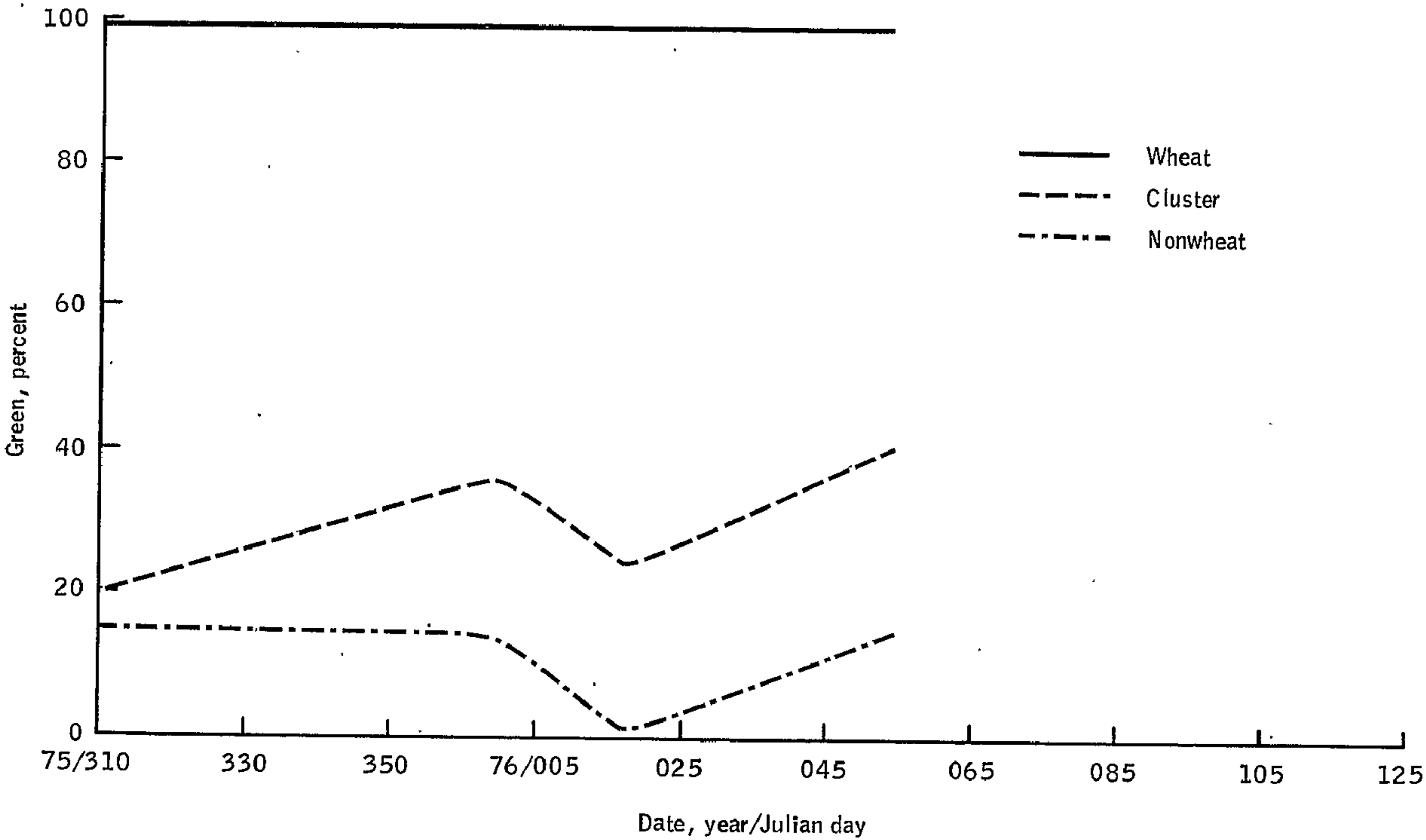

Figure 21. Drought effect upon segment 1892.

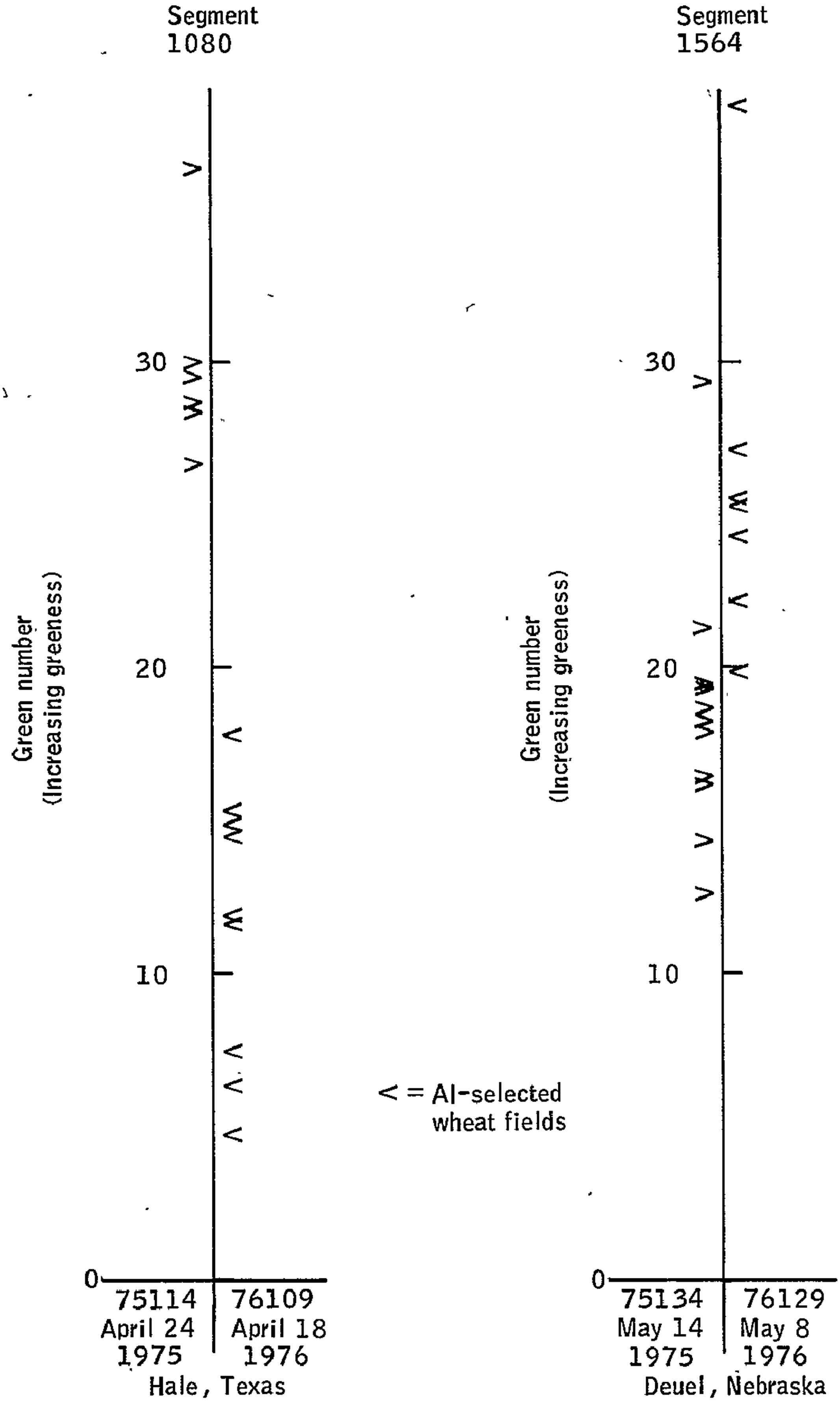

Figure 22. Drought effect upon individual wheat fields.

covered images. Some of the quality deficiencies noted were:

1. Original and duplicate copies did not have same color qualities. The step wedges were noticeably different.

2. Severe graininess on both Landsat I and Landsat II images (compared to Landsat I images of 1973 and 1974) caused a mottled, multi-colored texture to most features. This graininess was also notieceable on the step wedges.

3. Landsat II images appear more yellowish and brighter than Landsat I images.

4. The eastern half of each image appears slightly darker than the western half.

5. In the side-overlap area of two successive orbits, the scene from the western orbit appears darker than the same scene from the preceding day's eastern orbit.

There was some problem in acquisition of less than 70% cloud for full-frame images. Images were not sent to JSC because of greater than 70 percent cloud cover for Landsat II and Landsat I was not turned on because of the probability of cloud cover. The images sent to JSC are shown in figure 23. The problem was primarily one that key images were missing over the drought area (acquisition of March 4, 14, 31, 1976; April 2, 19, 27, 28, 29, 1976). Although cloud cover greater than 50 percent did cause some problem, the images were still somewhat usable. As it turned out the original area designated as having drought damage was larger than the actual area. If the original area had all

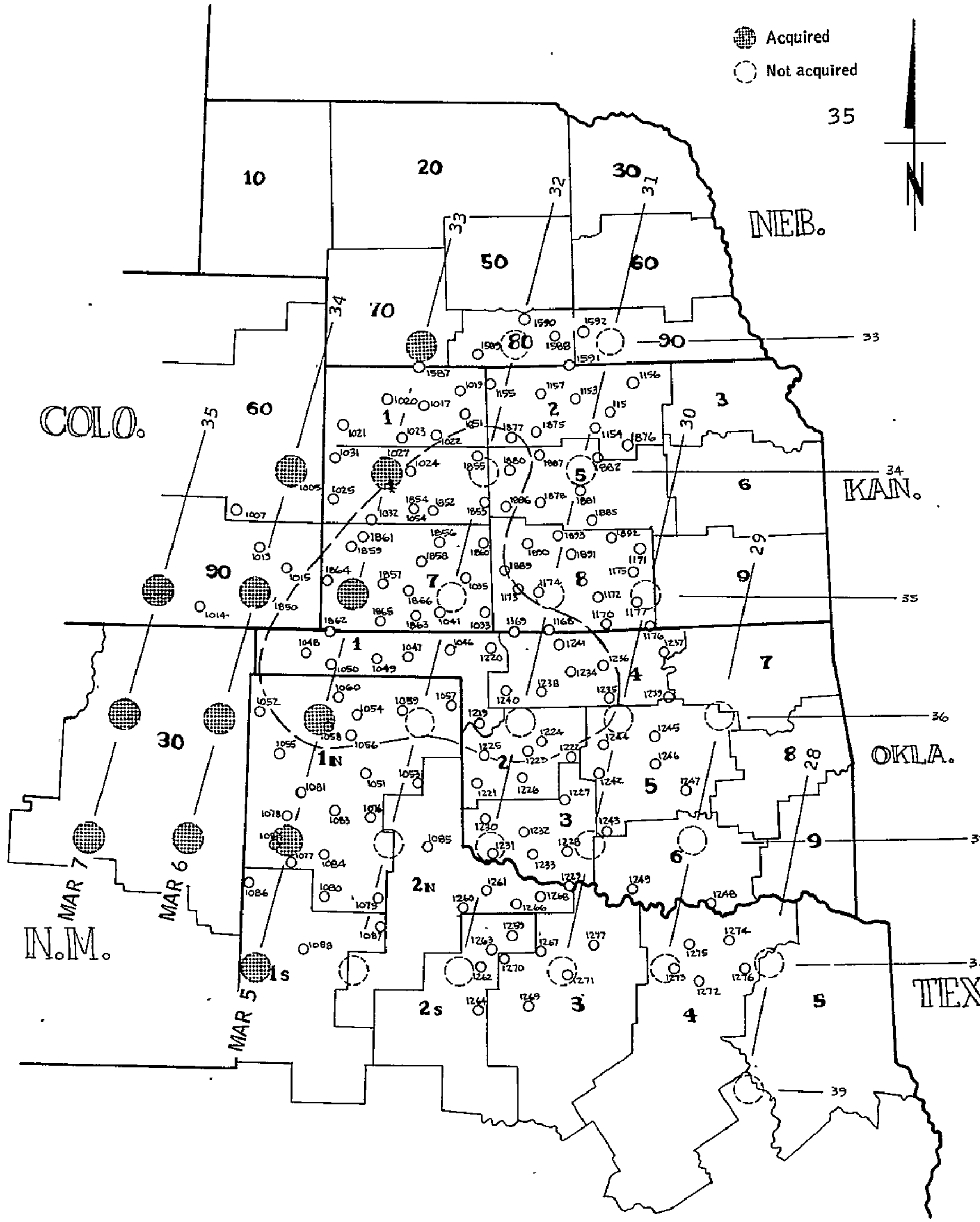

FIGURE 23. ACQUISITION HISTORY OF FULL FRAME IMAGES.

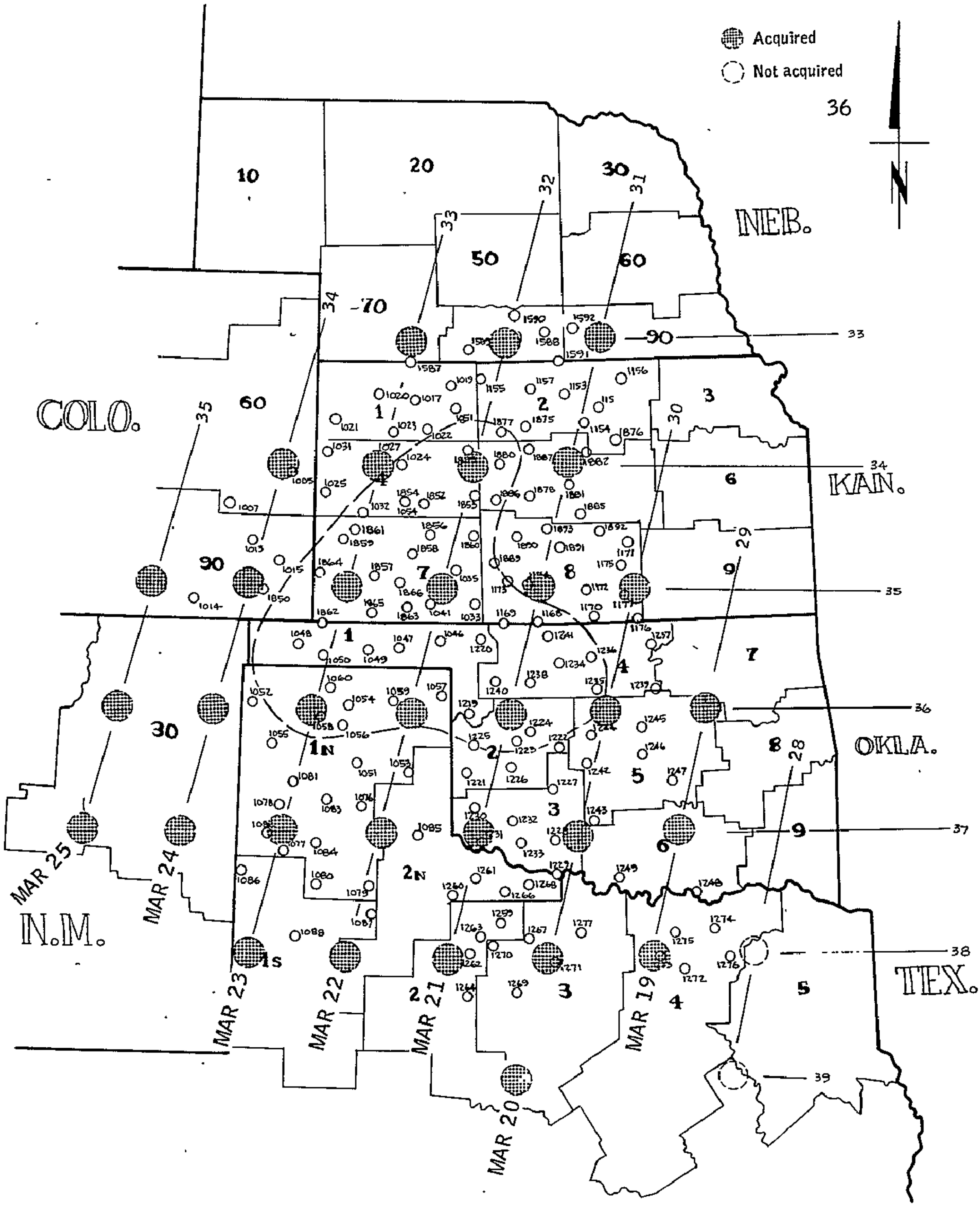

FIGURE 23. CONTINUED

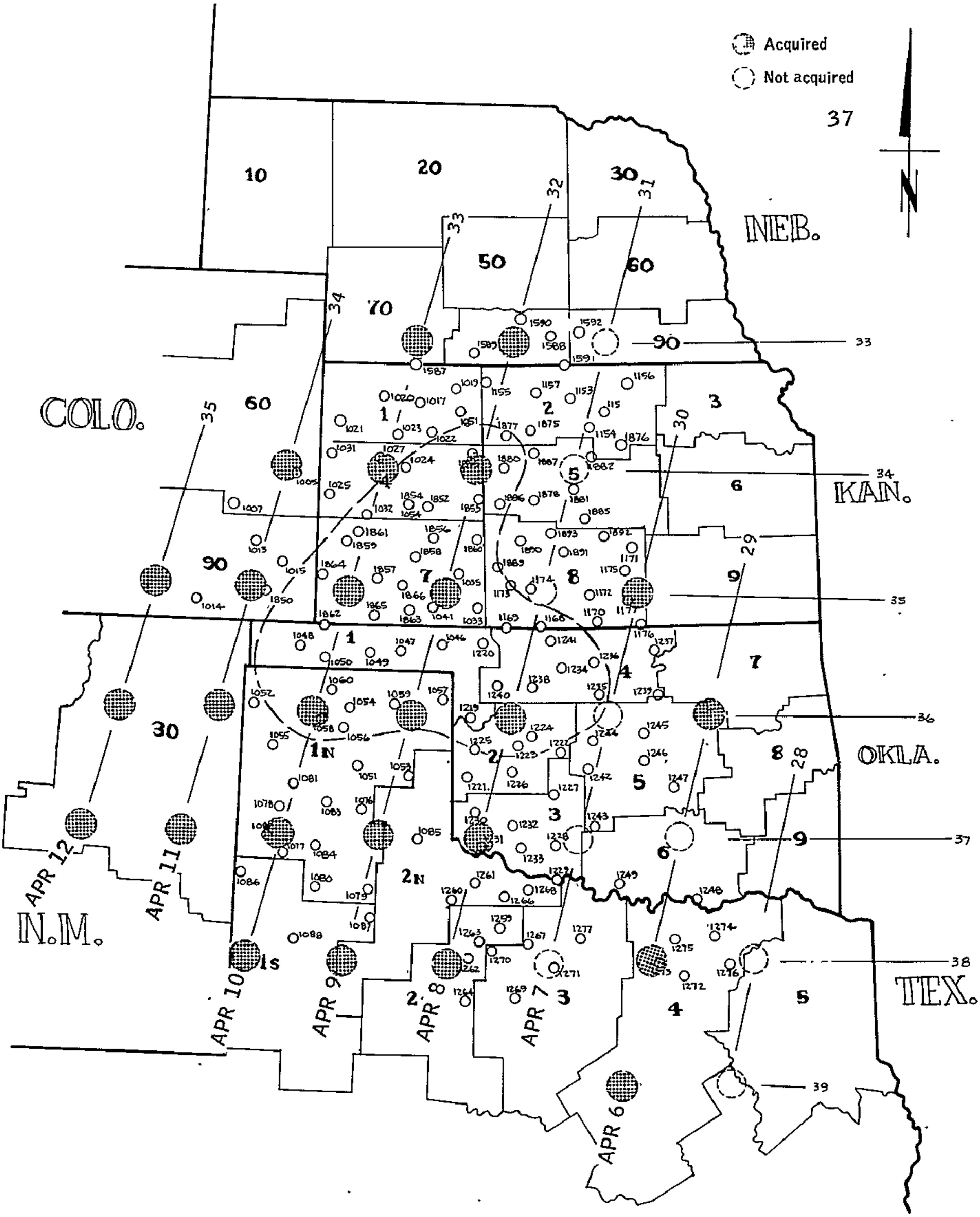

FIGURE 23. CONTINUED

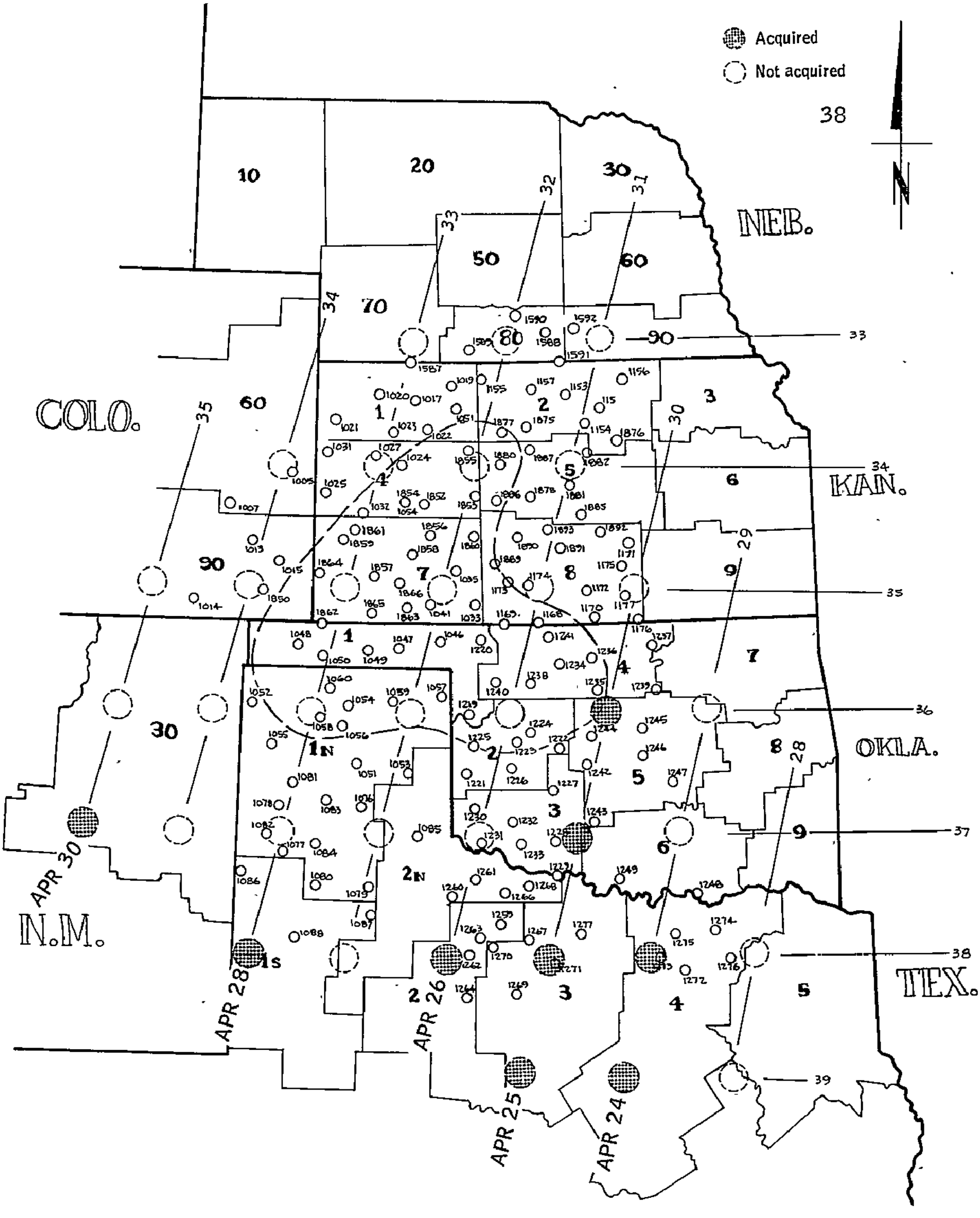

FIGURE 23. CONTINUED

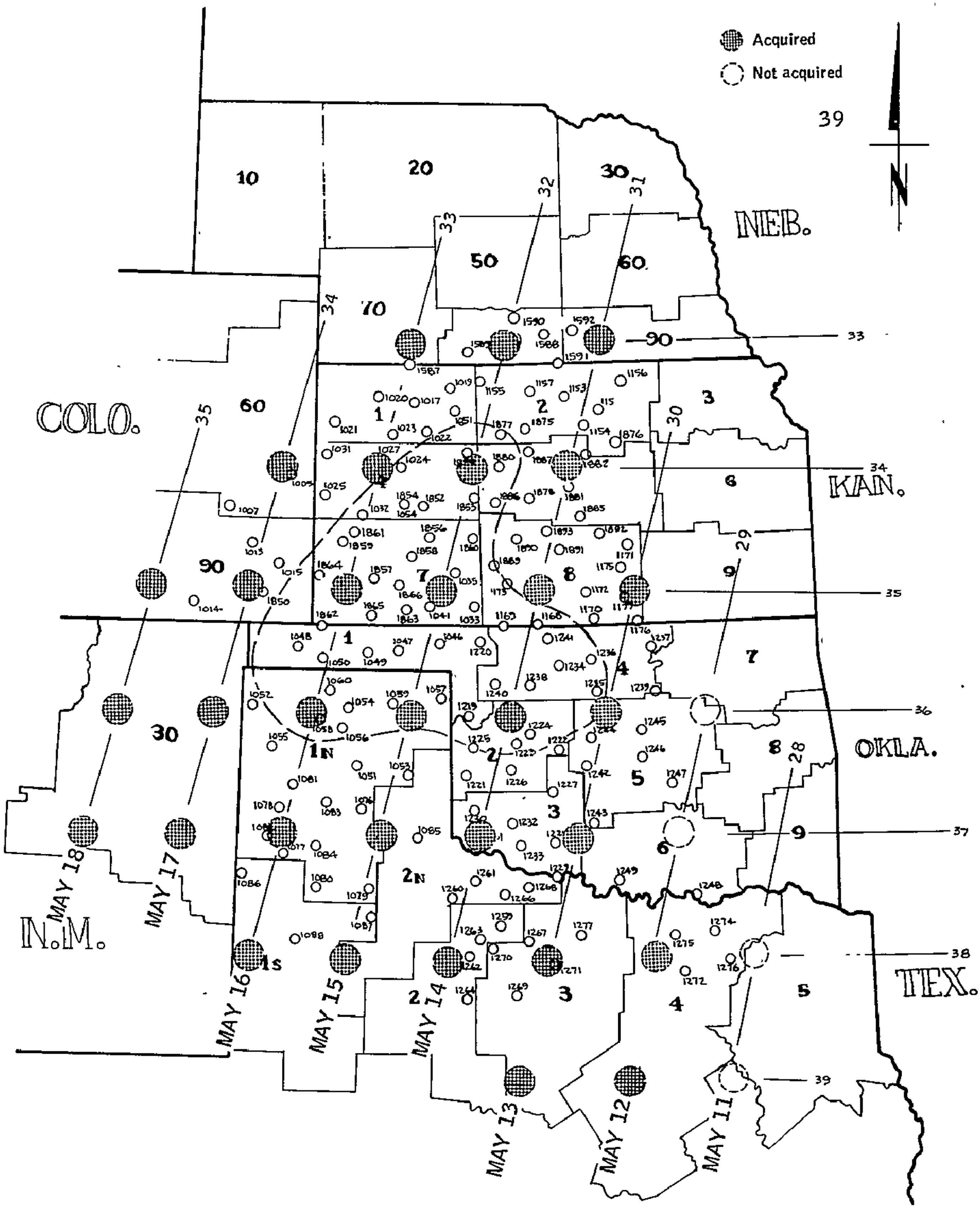

FIGURE 23. CONTINUED

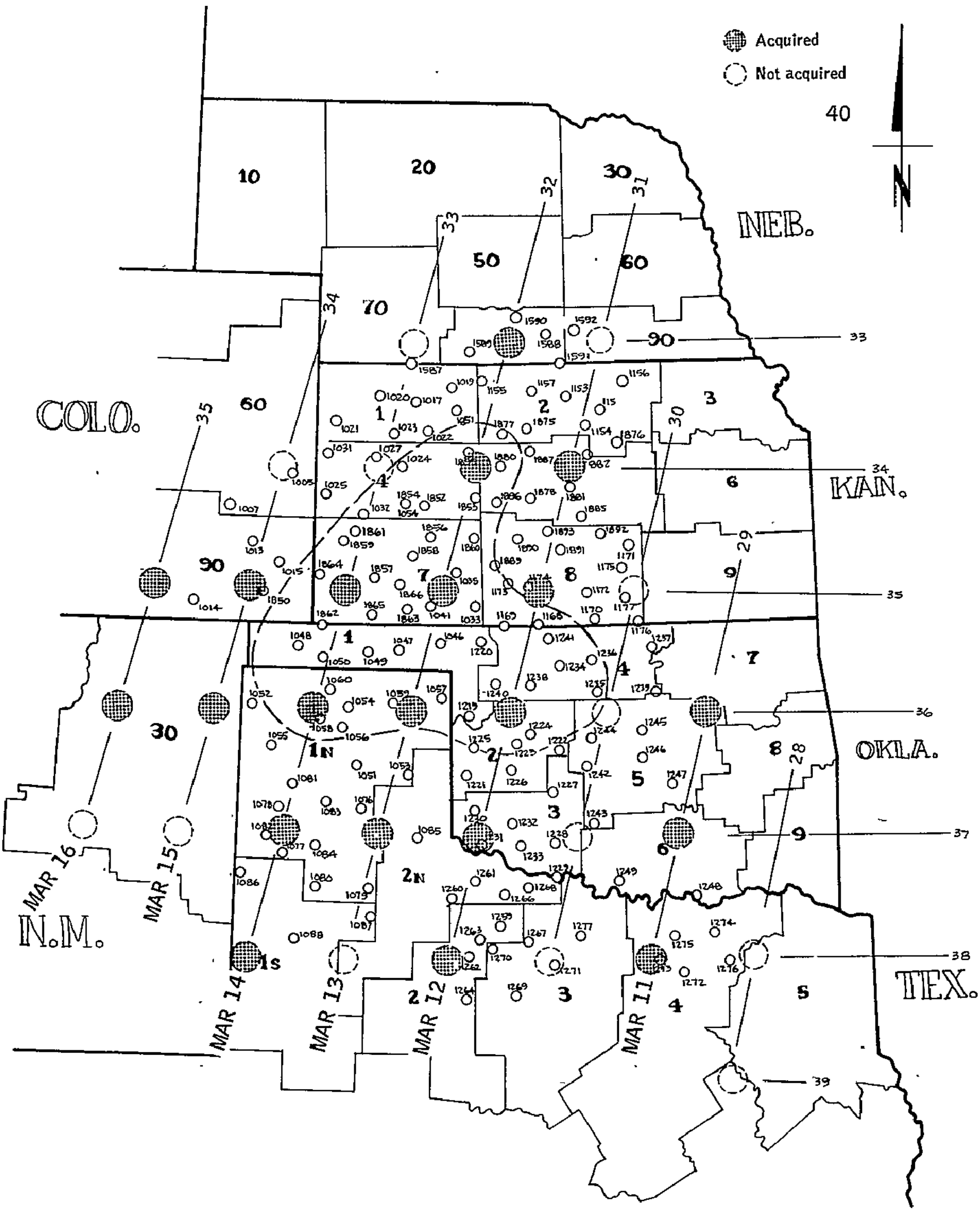

FIGURE 23. CONTINUED

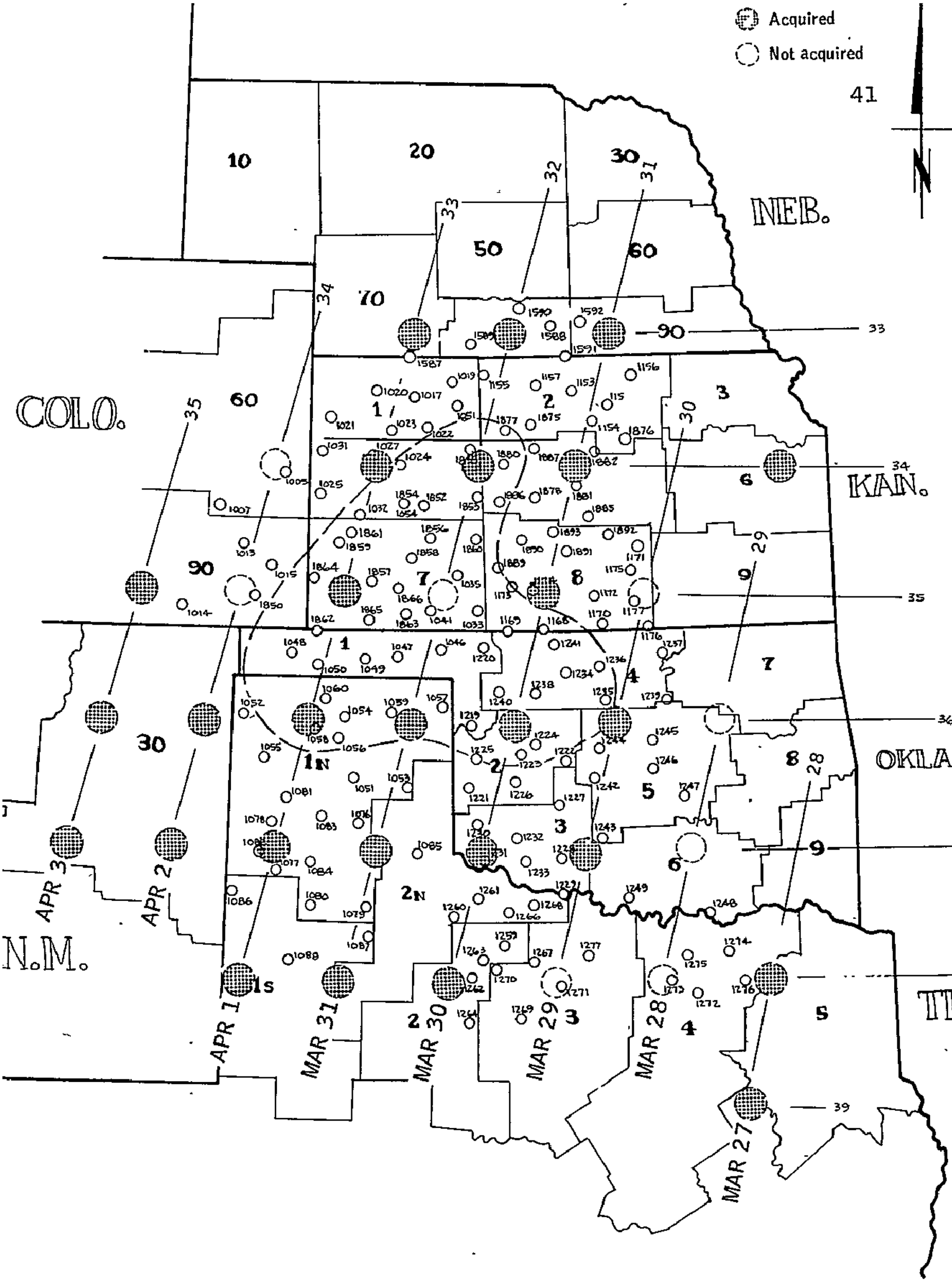

FIGURE 23. CONTINUED

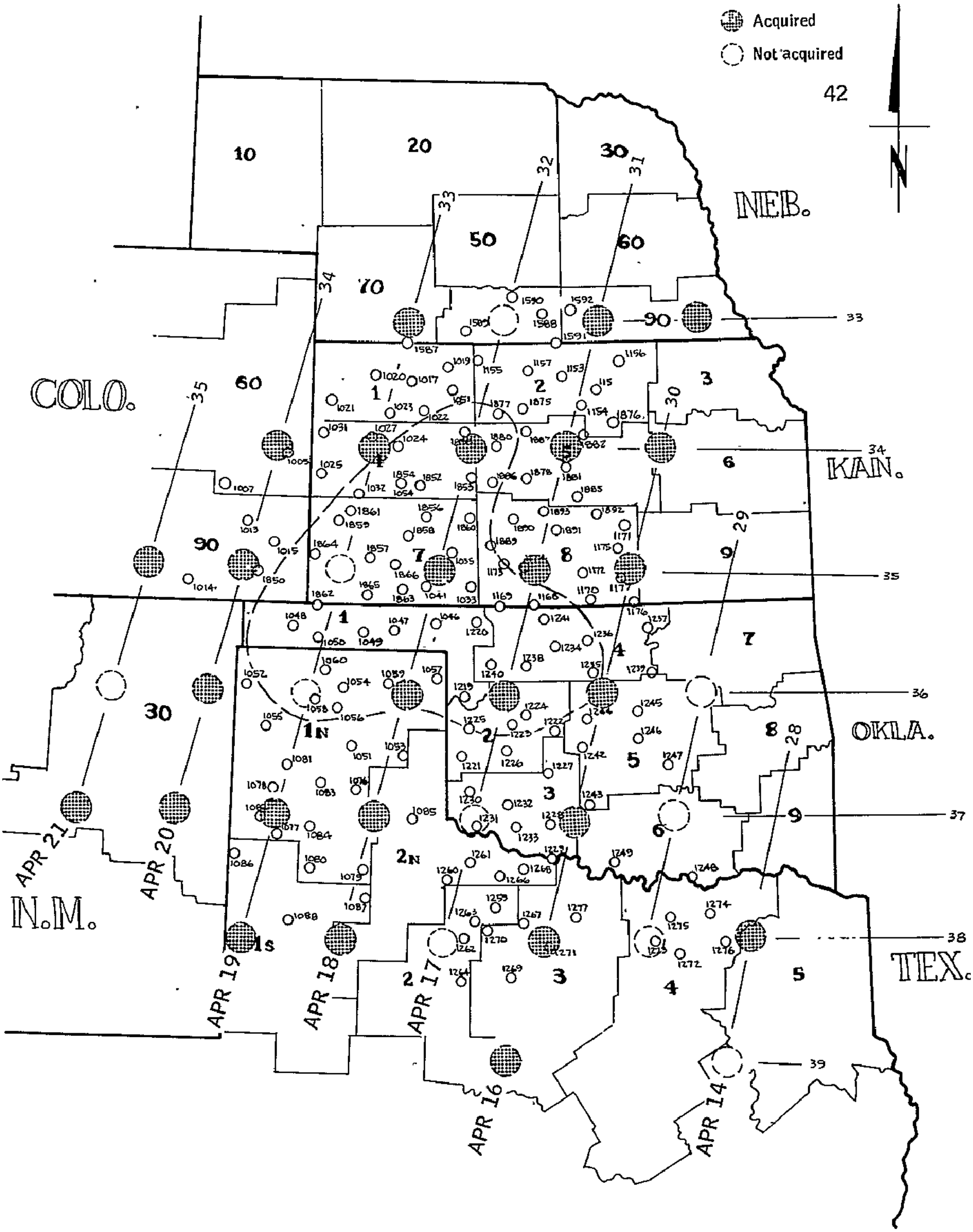

FIGURE 23. CONTINUED

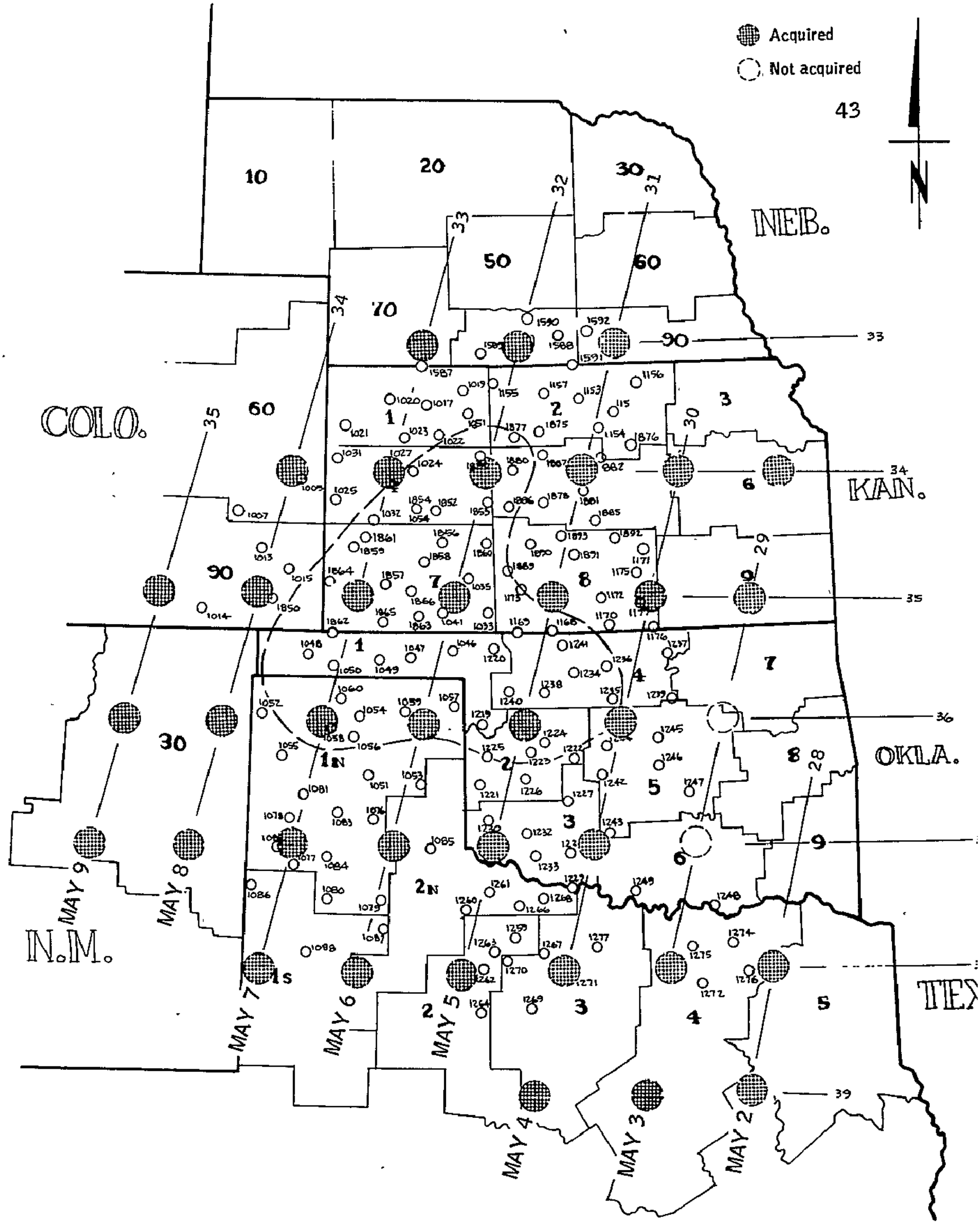

FIGURE 23. CONTINUED

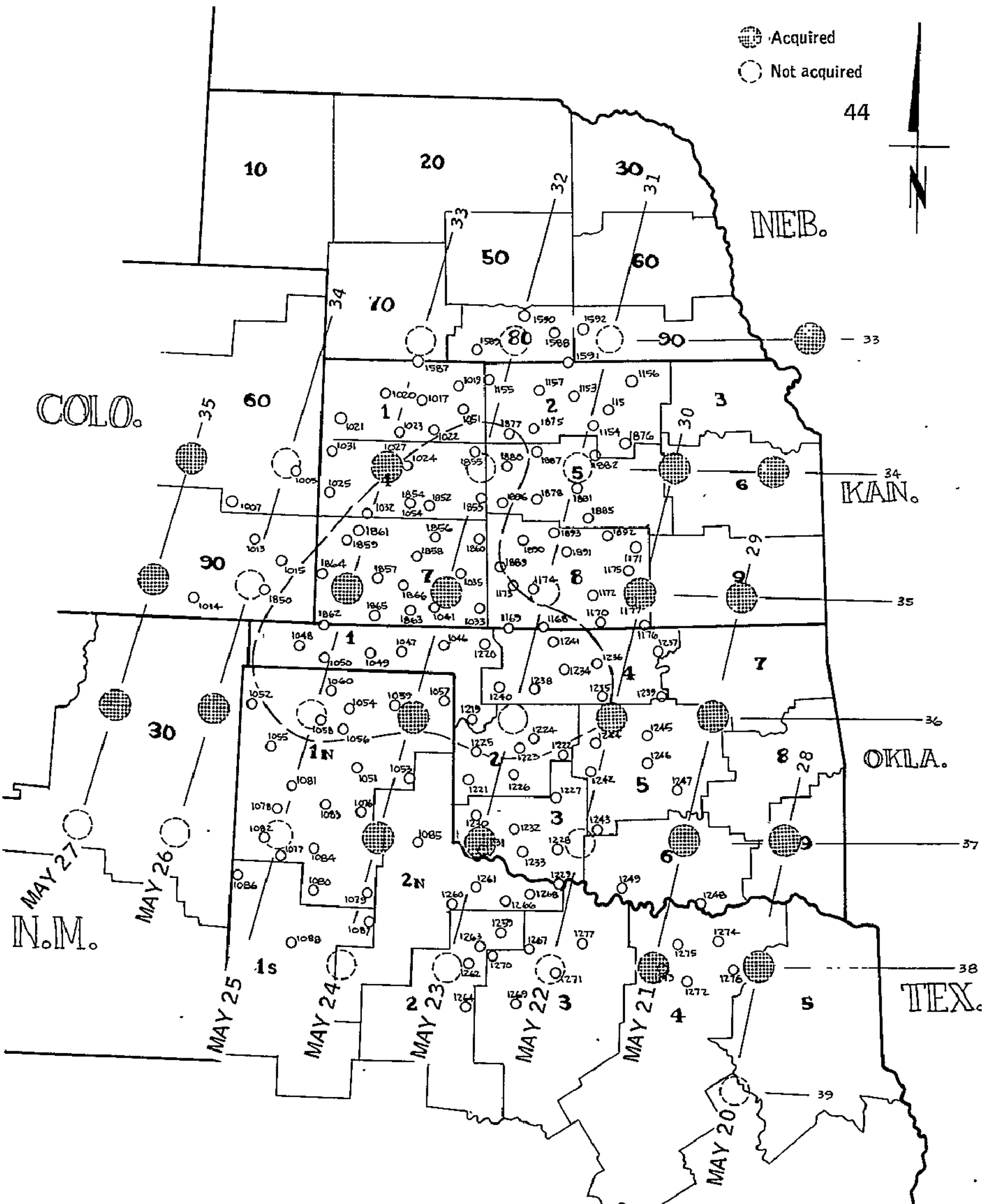

FIGURE 23. CONTINUED

actually been affected, a serious problem would have occurred in not having good coverage of that area (figure 23).

2.4 Summary of Areal Delineation

Landsat full-frame imagery can be used to outline drought affected areas. Landsat imagery provides a method of subjectively rating the outlined area. The Crop Moisture Index provides the general area having potential drought damage but does not entirely agree with areal extent from full-frame. The Crop Moisture Index does not agree because it is a meteorological indication of drought and water requirements for different growth stages are not reflected in the index. Full-frame imagery provides an integration of factors that affect vegetative growth.

The Kauth transformation of greenness appears to be useful in quantifying the subjective ratings of the drought area. It also appears to provide a method of quantifying the effect that drought has upon vegetative greenness of wheat compared to normal years.

Landsat appears to provide an earlier response to the actual area affected by drought than the Crop Moisture Index or meteorological data. It is necessary to have 9-day coverage of Landsat if an episodal event is to be monitored over a large area because of cloud cover.

In order to locate, delineate, or evaluate drought damage, Landsat imagery and meteorological data must be used conjointly. There does not appear to be a single piece of data that answers all the questions.

3.0 Landsat Survey for Precipitation Patterns and Effectiveness

The drought provided an opportunity to test the applicability of surveying Landsat data for precipitation patterns and effectiveness. Currently, weather station data are used in yield models and, because of the location of the stations, may not accurately show the rainfall received by an area.

3.1 Theory for Landsat Precipitation Survey

The theory for using Landsat full-frames to monitor and outline areas that receive precipitation is that rainfall received before an overpass will darken the soil and thus be recorded by the sensor (figure 24).

If this precipitation is adequate for plant growth, Landsat will record a greening-up of the vegetation within the area receiving rainfall. If adequate precipitation is not received, there will be no greening-up (figure 24, dashed line). The weather station provides the amount of precipitation received. The example shows (figure 24) rainfall occurring before an overpass, 9 days later the area of the effect of the precipitation is smaller. Another rain of 1 inch occurred after this pass, the next Landsat overpass records this either as soil moisture or vegetation greening-up. The amount of precipitation received for the period would be 2 inches for the center area and 1 inch for the outer edges.

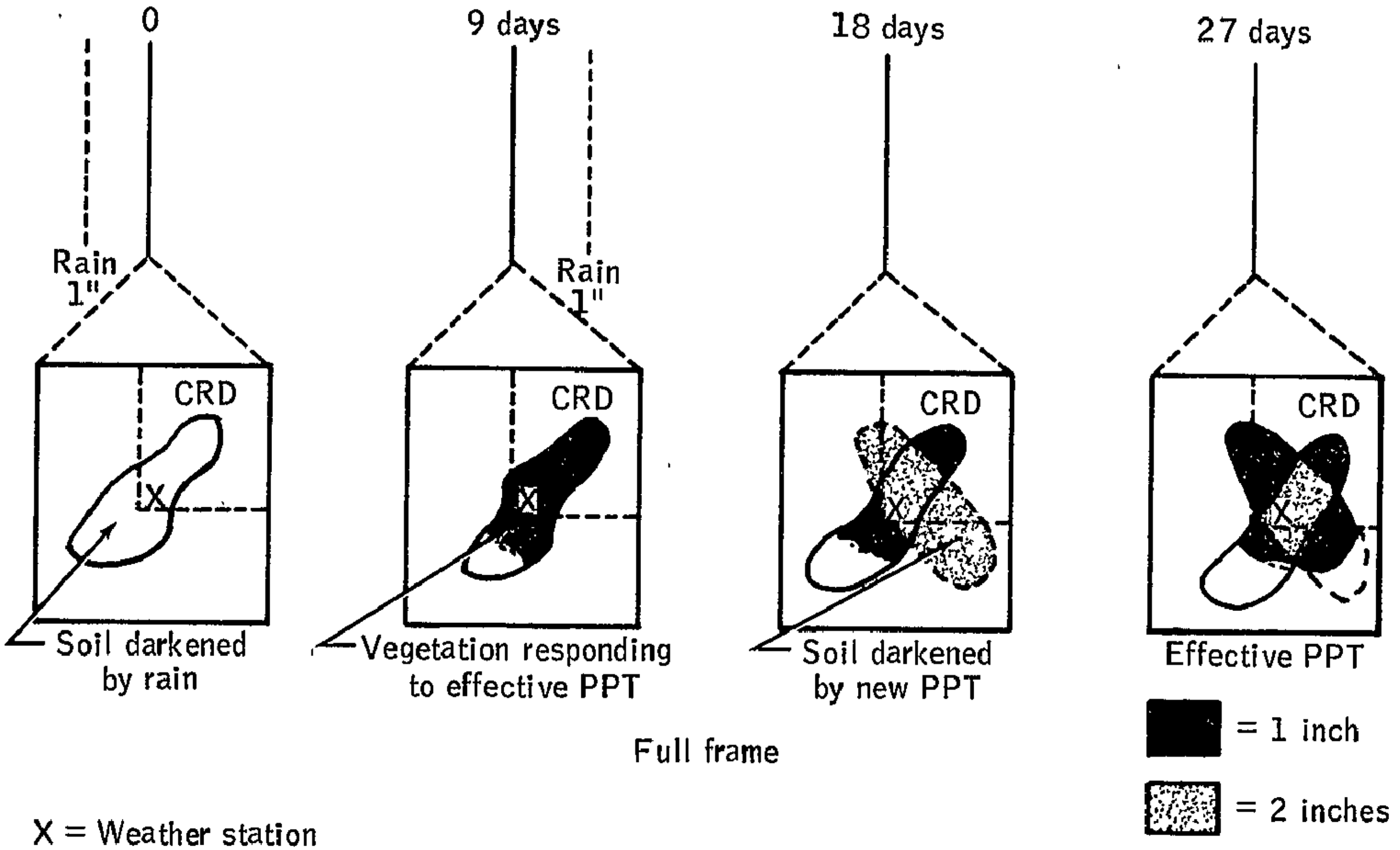

Figure 24. Theory for Landsat Precipitation Survey

3.2 Results of Landsat Precipitation Survey

Imagery was acquired starting March 1, 1976. No effective precipitation occurred within the drought area during March. During April, precipitation was received within the drought area. Full-frame imagery acquired April 9 through 12, 18 through 21, and May 6 through 8, 1976, were used to outline areas receiving precipitation and amounts. The April 27 through 30, 1976 imagery was not obtained because of cloud cover and the May 6 through 8, 1976 imagery was used to measure the effective precipitation that occurred after the mid-April overpass.

Total precipitation that occurred over the drought area for April 1 through 10, 1976 is shown in figure 25. The pattern of rain shows that light precipitation occurred over western Kansas with little or no rain visible on full-frame for other areas. Total precipitation for April 11 through 18, 1976 (figure 26) shows that heavy rains occurred in central Kansas and western Oklahoma and Texas. The western part of Kansas and Texas and the Oklahoma Panhandle received moderate precipitation with the rest of the area receiving light precipitation. The Landsat overpass for the last of April was cloud covered. Using weather station data for April 18 through 30, 1976, precipitation and the May 6 through 8, 1976 Landsat pass for greening-up effects, the overall total precipitation for April is shown in figure 27.

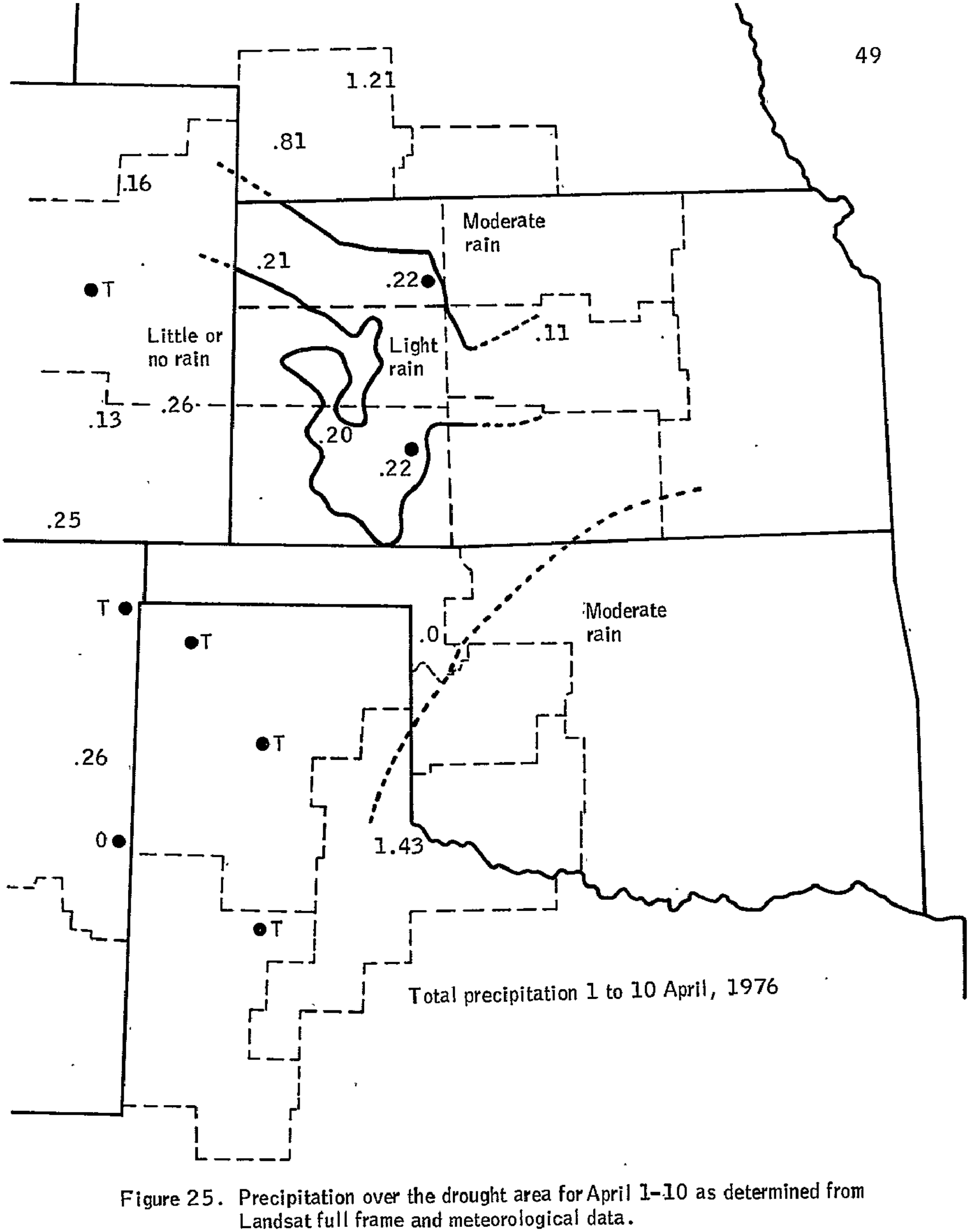

Figure 25. Precipitation over the drought area for April 1-10 as determined from Landsat full frame and meteorological data.

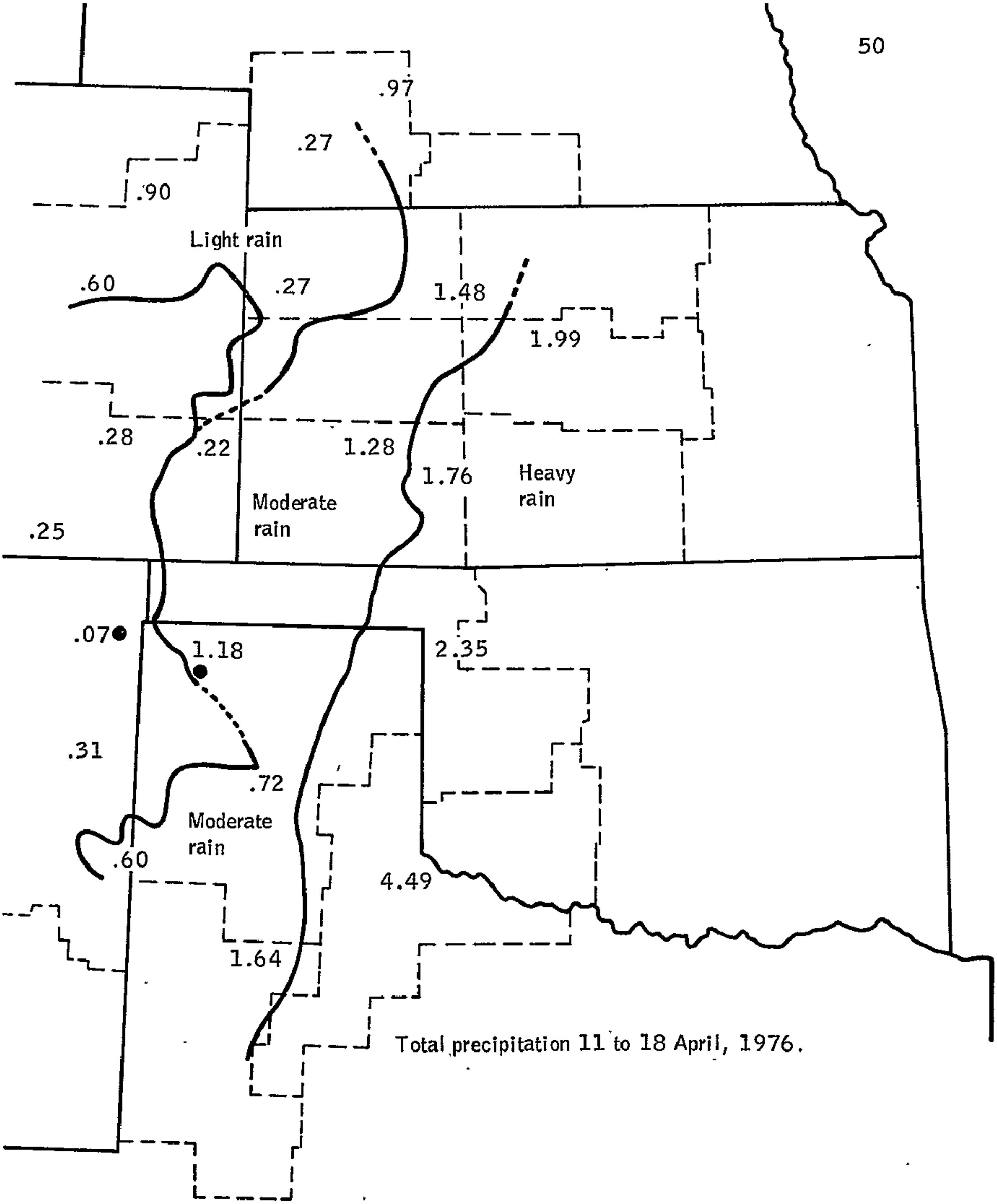

Figure 26.- Precipitation over the drought area for April 11-18 as determined from Landsat full frame and meteorological data.

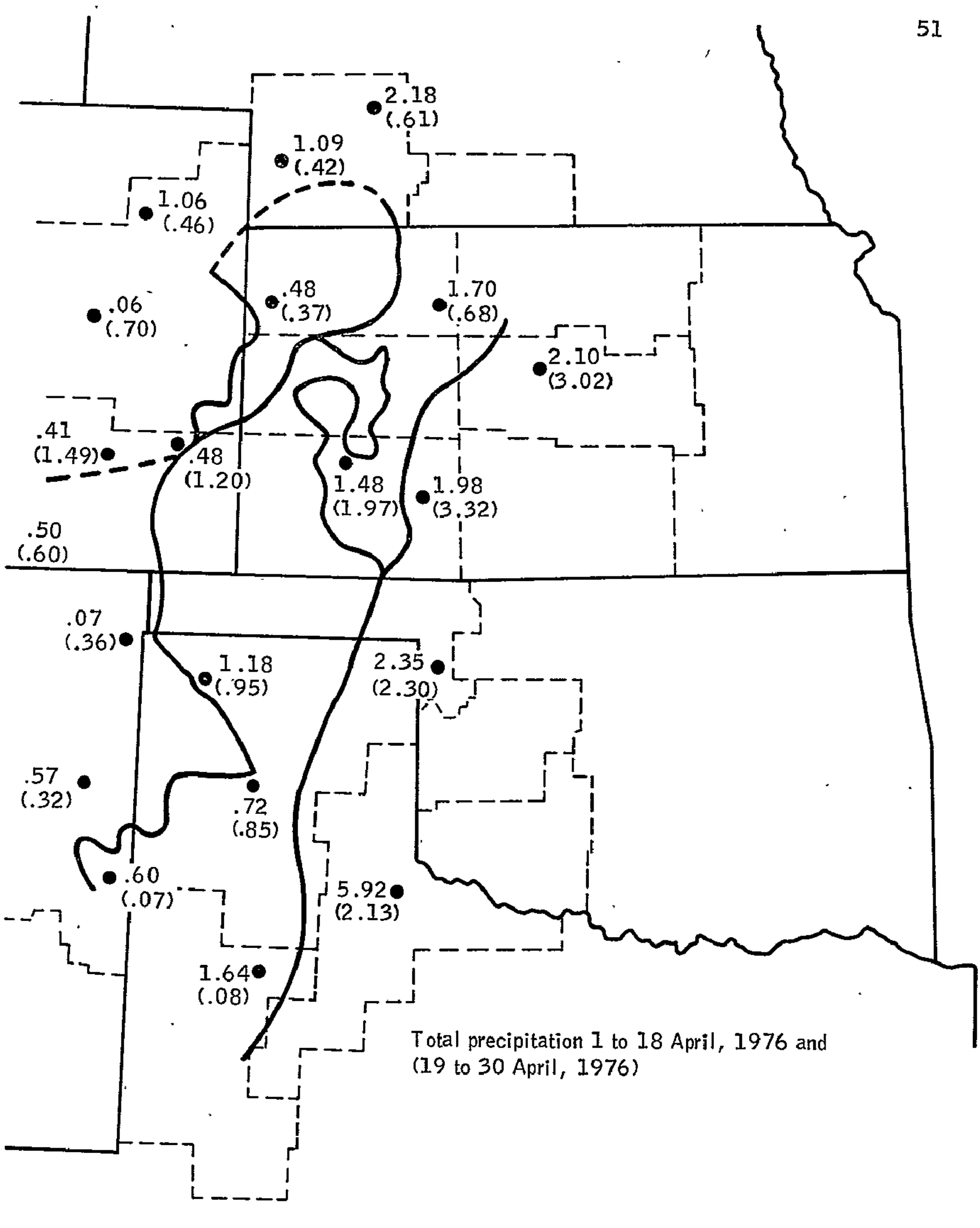

Figure 27. Overall precipitation for April as determined from Landsat full frame and meteorological data.

The precipitation effect determined from Landsat full-frame varies somewhat from the normal meteorological isoline map for April (figure 28). From figure 27, the amount of precipitation received by crop reporting districts can be determined as shown in table 1.

3.3 Conclusion of Landsat Precipitation Survey

Landsat full-frame imagery was successfully used within the drought area to improve precipitation patterns and effectiveness. It was not successful outside the drought area because the timing of acquisition was not exactly right to monitor the effect of soil and vegetation. Vegetation is responding (greening-up) not only to current precipitation but also to availability of subsoil moisture.

The ability to monitor and improve precipitation patterns is important because, if precipitation is not received during the most vulnerable time, yield will be reduced. Also, in order to monitor precipitation patterns, 9-day coverage will be required.

4.0 Drought Affected Acreage

The effects of drought on the wheat acreage were conducted using standard LACIE operational procedures. Landsat I was used to fill in segments not acquired by Landsat II and also to monitor changes in the segment during the drought analysis period. All segments within the original drought area were evaluated, however, only the drought affected CRD's as defined by the drought study will be reported on insofar as acreage, yield, and production in this report. The results for outside the drought area are available if needed.

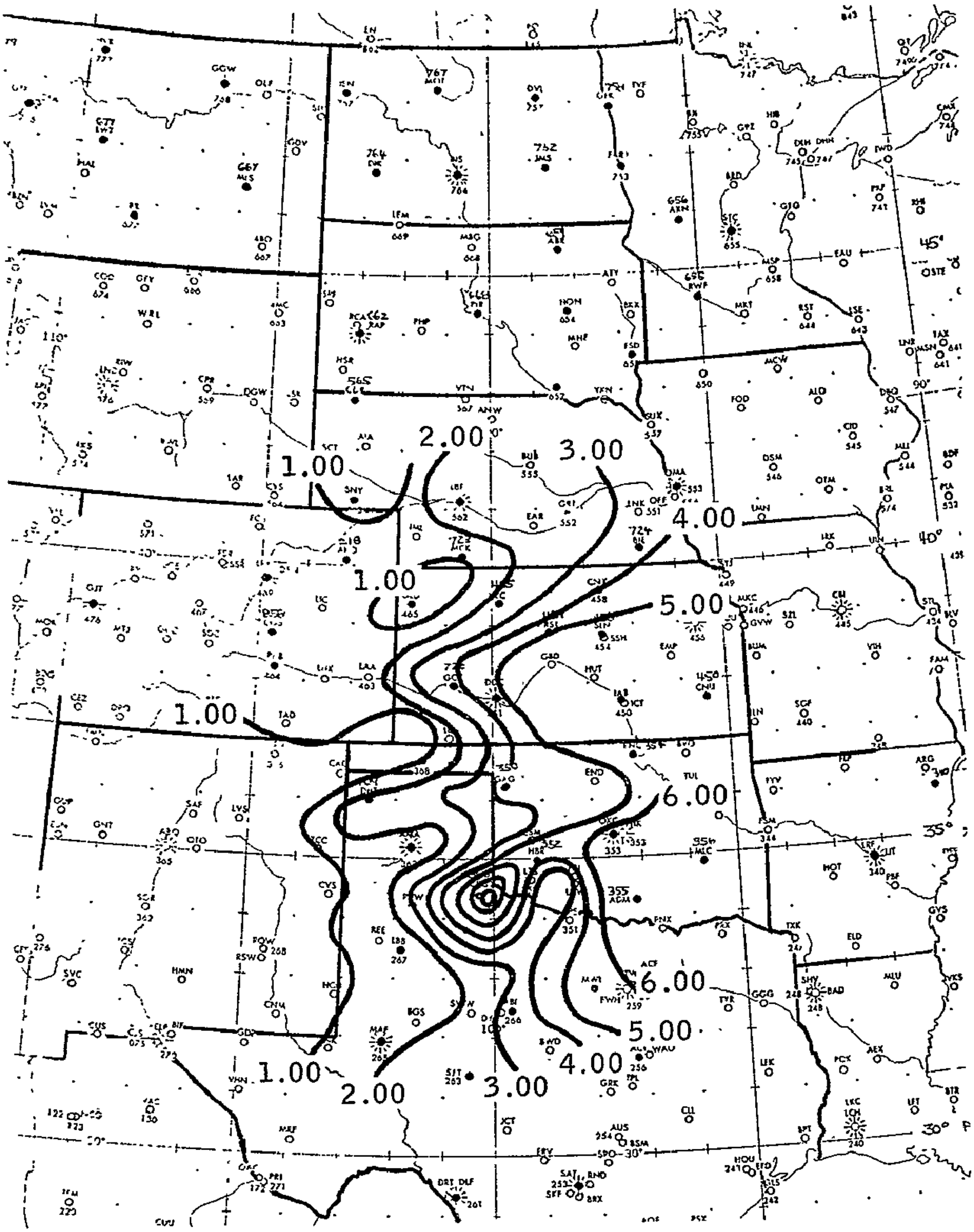

Figure 28. - Total precipitation - April 1976

Table 1. April precipitation effectiveness by CRD's as determined from Landsat.

CRD	April Amount of Precipitation Inches
Kan. 1	.73
	2.4
4	.73
	2.5
7	5.3
	3.5
	1.5
Okla. 10	4.6
	1.5
Texas 11	.5
	1.5
	2.1
	4.6

Table 2. Acreage results for drought area from Landsat I and/or II and historical acres.

		ACREAGE*				
		APRIL		MAY		HISTORICAL (1975 Harvested)**
State	CRD	L2	L1, L2	L2	L1, L2	
Colo.	60	1503	1503	1503	1503	1360
	90	205	205	218	218	365
Kan.	1	1266	1266	1201	1201	1161
	4	1289	1289	1125	1142	1288
	7	525	525	766	766	1936
Okla.	10	108	84	117	117	1094
Tex.	11	1360	1360	1261	1367	2720
	12	156	156	263	263	340

* Thousands
** SRS results

From table 2, Kansas CRD 7, Oklahoma CRD 10, and Texas CRD 1 were most severely affected by the drought. These areas occurred in the severely rated drought affected area as determined from the full-frame imagery.

5.0 Yield Predictions

The Center for Climatic and Environmental Assessment (CCEA) regression models are not tuned to be highly responsive to events such as severe drought. Some additional steps were taken using these models to provide support to the drought study and also to evaluate if these approaches improved the response of the yield models.

The additional steps taken were to:

a. Using the proper truncation, weather to date plus a 30-day forecast.

b. Weather to date plus 10 percentile of precipitation to end of season.

c. Weather date plus 90 percentile of precipitation to end of season.

d. Landsat survey of precipitation for areal extent of precipitation.

e. The models which were developed for state were run for CRD's.

5.1 Yield Results

The yield models' results (table 3) in the drought area showed little variation between the standard or normal yield and the

Table 3. Yield results for drought affected CRD's.

		APRIL				MAY			
	CRD	STD	10%	90%	30DF	STD	10%	90%	30DF
Kan.	1	29.1	28.9	29.4	29.2	28.3	28.4	30.0	30.1
	4	28.2	27.9	28.5	28.3	28.0	27.9	28.8	29.3
	7	27.0	26.8	27.2	27.2	26.7	26.3	27.8	28.3
Colo.	60	19.4	18.4	20.2	20.2	18.7	19.0	21.7	21.0
	90	21.2	20.9	21.7	21.7	20.7	20.9	23.0	22.6
Okla.	10	17.8	17.6	20.0	20.0	20.7	21.4	21.8	22.2
Tex.	11	17.2	17.2	19.2	19.0	19.7	20.2	20.7	20.4
	12	17.2	17.2	19.2	19.0	19.7	20.2	20.7	20.4

special yields. The actual difference in most cases was about one bushel between 10 percent of normal (dry) and 90 percent of normal (wet) and the 30-day forecast. However, when the yield models were run using April precipitation as determined from full-frame, a larger variation did occur. If a comparison is made between tables 3 and 4, it is apparent that the Kansas yield model did not respond to different amounts of precipitation while the other states' models did. For each additional inch of rain, the Texas model increased yield about one bushel (table 4). The Oklahoma and Colorado models also show a similar response.

It is apparent from these results that the lack of response from the Kansas yield models needs to be investigated since the other states' yield models responded to different amounts of precipitation.

Also the censoring of actual precipitation at 90 percent of normal distribution is questionable. If the precipitation fell in a single storm, this censoring might be valid, however, this probably does not happen and the soil could absorb and store most of the moisture that fell.

Table 4. April Precipitation amounts as determined from Landsat full frame and corresponding yields using CCEA May yield models.

APRIL PRECIPITATION (FULL FRAME)

(May Yield Model)

State	CRD	Actual	CRD Yield
Kan.	1	0.73"	28.72
		2.4	29.07
	4	0.73	27.90
		2.5	28.28
	7	5.3	27.61
		3.5	27.23
		1.5	26.81
Okla.	10	1.5	21.19
		4.6	25.69*
Tex.	11	0.5	18.99
		1.5	20.34
		2.1	21.16*
		4.6	24.54*
Colo.	90	1.68	21.84
		1.1	21.00
	60	not determined	

* Actual precipitation would be censored at 90% of normal distribution.

5.2 Yield Conclusions

It is apparent that the Kansas CCEA yield model is not responding similar to other states' yield models in the drought area. This lack of response needs to be examined in greater detail. Also, the censoring of 90 percent of normal precipitation should be examined when the models are run for drought conditions.

6.0 Drought Aggregation

Aggregations for the drought area were a subset of the total Great Plains aggregation run. Aggregations were done for Landsat 2 data only and Landsat 1 plus Landsat 2 data for the different CCEA yield results.

6.1 Landsat 1 Versus Landsat 2

One question to be answered from the drought study is the utility of having two satellites. The study of the utility of two satellites will continue until harvest. Initial CAMS operational results do not support having two satellites (table 5), however, because of the long biowindow 1 resulting from extending drought, this may not be true for other biowindows. Only three additional segments were acquired by Landsat 1 during this time period.

6.2 Production Estimates

Production involves taking acreage estimates and multiplying times yield estimates. Thus, the production estimates are only as accurate as the acreage or yield estimates. The production for Landsat 2 data only is given in table 6. When compared to Landsat 1 and Landsat 2 production (table 7), the only difference is in CRD's that had the additional Landsat 1 acquisitions.

Table 5

SUMMARY OF SEGMENTS ALLOCATED AND SEGMENTS USED IN "DROUGHT" AGGREGATIONS DURING APRIL AND MAY, U.S. GREAT PLAINS

CRD's by state	Number of segments allocated	Number of Segments Used in "Drought" Aggregations			
		April		May	
		L-2 only	L-1 and L-2	L-2 only	L-1 and L-2
Colorado					
CRD-10	3	0	0	0	0
CRD-20	7	6	6	6	6
CRD-60	14	14	14	14	14
CRD-70	3	1	1	1	1
CRD-80	0	0	0	0	0
CRD-90	5	4	4	5	5
	32	25	25	26	26
Kansas					
CRD-1	8	7	7	8	8
CRD-2	11	8	8	8	8
CRD-3	4	2	2	2	2
CRD-4	9	6	6	7	8
CRD-5	11	8	8	9	9
CRD-6	5	4	4	5	5
CRD-7	14	11	11	13	13
CRD-8	15	9	9	10	10
CRD-9	7	7	7	7	7
	84	62	62	69	70
Oklahoma					
CRD-10	7	5	6	6	6
CRD-20	6	6	6	6	6
CRD-30	7	7	7	7	7
CRD-40	8	6	6	7	7
CRD-50	6	6	6	6	6
CRD-60	2	2	2	2	2
CRD-70	3	3	3	3	3
CRD-80	1	1	1	1	1
CRD-90	0	0	0	0	0
	40	36	37	38	38

Table 5 (cont.)

SUMMARY OF SEGMENTS ALLOCATED AND SEGMENTS USED IN "DROUGHT" AGGREGATIONS DURING APRIL AND MAY, U.S. GREAT PLAINS

CRD's by state	Number of segments allocated	Number of Segments Used in "Drought" Aggregations			
		April		May	
		L-2 only	L-1 and L-2	L-2 only	L-1 and L-2
Texas					
CRD 11	19	17	17	18	19
CRD-21,22	12	11	11	12	12
CRD-30	5	4	4	5	5
CRD-40	5	3	3	4	4
CRD-51,52	0	0	0	0	0
CRD-60	0	0	0	0	0
CRD-70	2	2	2	2	2
CRD-81,82	3	3	3	3	3
CRD-90	0	0	0	0	0
CRD-96,97	0	0	0	0	0
CRD-12	3	2	2	3	3
	49	42	42	47	48

TABLE 6

PRODUCTION*

LANDSAT 2

		APRIL				MAY			
STATE	CRD	CMR ESTIMATES	10%	90%	30DF	CMR ESTIMATES	10%	90%	30DF
COL	60	29,164	27,662	30,668	29,015	28,113	28,564	32,623	31,570
	90	4,341	4,280	4,444	4,383	4,505	4,548	5,005	4,918
KAN	1	36,853	36,600	37,234	36,980	34,698	34,097	35,658	36,138
	4	36,345	35,959	36,732	36,475	31,493	31,380	32,392	32,955
	7	14,183	14,078	14,288	14,288	20,458	20,151	21,301	21,684
OKLA	10	1,913	1,892	2,150	2,150	2,426	2,508	2,555	2,602
TX	11	23,389	23,390	26,109	25,837	24,837	25,467	26,098	25,719
	12	2,679	2,680	2,992	2,960	5,176	5,308	5,439	5,360

*THOUSANDS

TABLE 7

PRODUCTION*

LANDSAT 1 AND LANDSAT 2

		APRIL				MAY			
STATE	CRD	CMR ESTIMATES	10%	90%	30DF	CMR ESTIMATES	10%	90%	30DF
COL	60	29,164	27,662	30,668	29,015	28,113	28,564	32,623	31,570
	90	4,341	4,280	4,444	4,383	4,505	4,548	5,005	4,918
KAN	1	36,853	36,600	37,234	36,980	34,698	34,097	35,658	36,138
	4	36,345	35,959	36,732	36,475	31,493	31,872	32,900	33,471
	7	14,183	14,078	14,288	14,288	20,458	20,157	21,301	21,684
OKLA	10	1,913	1,484	1,687	1,687	2,426	2,508	2,555	2,602
TX	11	23,389	23,390	26,109	25,837	24,837	27,613	28,297	27,887
	12	2,679	2,680	2,992	2,960	5,176	5,308	5,439	5,360

*THOUSANDS

7.0 Summary and Recommendations

7.1 Summary

The objectives of the LACIE integrated drought plans were met. Meteorological data was used to signal the potential for drought damage. Full-frame Landsat imagery was used to delineate the areal extent and subjectively rate the drought area. Landsat full-frame was used to survey April precipitation for areal extent of precipitation. Yield models were run using additional steps and production estimates were made for the drought affected CRD's.

7.1.1 Landsat

Landsat full-frame imagery provided a fairly accurate way of determining areal extent of drought damage and agreed with other methods of locating drought. The affected area was subjectively rated as to drought effect upon vegetation. A linear combination of Landsat channel values were related to vegetation vigor and crop condition. The ratings within the drought area reflect soil moisture holding capacities. Landsat appears to provide more accurate and earlier response to actual area affected than CMI. Landsat full-frame provides a method of improving precipitation patterns and effectiveness. Addition of Landsat I did not support having two satellites for acreage determination because of long biowindows.

7.1.2 Meteorological Data

Meteorological data provides a method of flagging drought potential. The Crop Moisture Index (CMI) is the most suitable method, however, if the CMI is not available, precipitation totals can be used. A 25 to 30 percent of normal precipitation for two months before planting or 25 to 30 percent of normal precipitation for one month during the growing season would signal drought potential.

Landsat full-frame with weather station data provides a method of improving precipitation patterns and effectiveness. Precipitation distribution is of significance in relationship to crop growth stages to determine if a grain kernel is formed.

7.1.3 Production Estimates

Average was down in CRD's as determined from full-frame having drought damage. The yield models did not respond with much variation using 10th, 90th, and 30 DF. Colorado, Oklahoma, and Texas yield models responded using Landsat-determined precipitation. Production estimates varied according to area and yield estimates.

7.2 Recommendations

7.2.1 Landsat

Landsat coverage is needed on a 9 day interval for determination of areal extent and monitoring change over time. It does not appear that two satellites are needed for acreage determination.

7.2.2 Meteorological Data

Meteorological data provides the most easily available mehtod of signaling potential drought. This can be the CMI or precipitation totals where the CMI is not available in foreign areas.

7.2.3 Production Estimates

The present standard LACIE operational procedures provide a suitable method of determining the effect of drought on wheat acreage, however, the yield models do not appear to respond to drought effect. New yield models more responsive to episodal conditions may need to be developed. A comparison of vegetative vigor from Landsat digital data between normal and abnormal years may provide a method of reducing yield from the normal. While this is not the most acceptable method, until new yield models are brought into operation, this appears to be a way of reflecting reduction in yield because of drought. This theory needs to be tested in order to correlate the connection between vegetation vigor and yield.

8.0 Procedures for Monitoring Drought Using Remote Sensing Data

One objective of this study was to develop procedures for locating potential drought and monitoring the affected of drought over time. The steps necessary to locate and monitor potential drought are as follows:

1. Use meteorological data to signal potential drought area.

2. Determine vegetative greenness of segments within and outside potential area and evaluate against normal year.

3. If potential damage is indicated, use full-frame imagery in conjunction with segment greenness to outline areal extent. Full-frame imagery should be acquired on a 9 day coverage if available.

4. Using full-frame imagery, monitor precipitation for areal extent and effectiveness. Precipitation distribution is of significance because of relationship to crop growth stage as to whether a grain kernel is formed.

5. Sample segments would be monitored using normal operational procedures. In some cases it might be necessary for 9 day coverage if acquisitions are not being acquired at critical growth stages.

6. Generate specific yield results for affected area. Crop vigor comparison may give indication of yield reduction and a need to adjust yield results.

7. After harvest, continue to monitor meteorological data to determine if soil water is recharged, if not, potential for drought next crop year is present even if precipitation seems normal.

Appendix

Listing of CRD's in the Southern Great Plains Showing Old CRD Numbers.

State	Old CRD Numbers	Revised CRD Numbers
Colorado	10	--
	20	--
	60	--
	70	--
	80	--
	90	--
Kansas	1	10
	2	40
	3	70
	4	20
	5	50
	6	80
	7	30
	8	60
	9	90
Oklahoma	11,1	10
	24,2	20
	37,3	30
	42,4	40
	55,5	50
	68.6	60
	73,7	70
	86,8	80
	99,9	90
Texas	1, 1N, 1S	11
	2, 2N, 2S	(21
		(22
	3	30
	4	40
	5	(51
		(52
	6	60
	7	70
	8	(81
		(82
	9	90
	10	(96
		(97
	11	12